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FAA Technical Center
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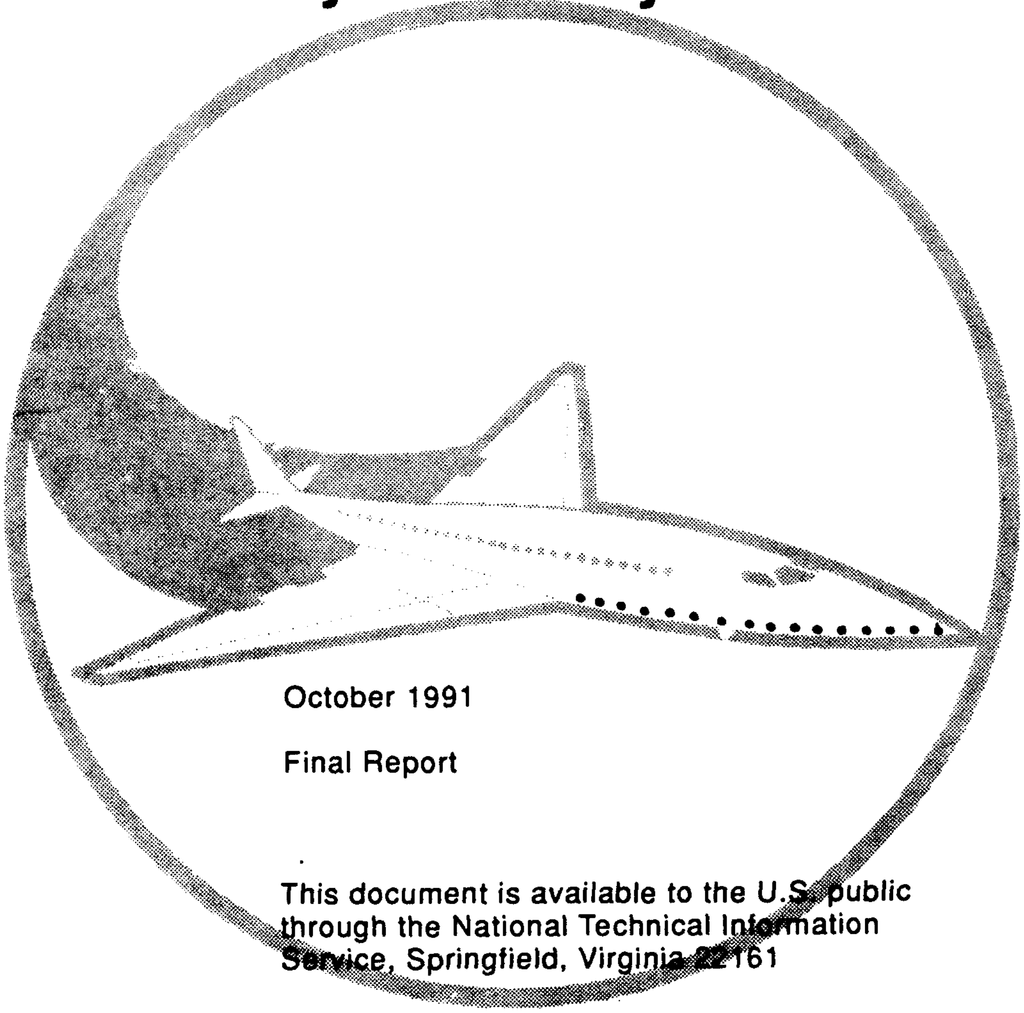
Turbine Engine Diagnostics System Study



October 1991

Final Report

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16. Abstract
This report presents the results of a system study for the Turbine Engine Diagnostics (TED) program. This research project was initiated to develop a method of approach and prototype design for a system capable of predicting the failure of rotating parts in turbine engines. Systems Control Technology (SCT) Inc. was contracted by the Federal Aviation Administration (FAA) and used an innovative approach that assimilated data from multiple sources for determining trends in engine performance and health. SCT initially performed an extensive technical literature search and industry survey to augment the present understanding of current technology in the industry for computerized diagnostic systems and measurement sensor technology. The result of this study is a proposed system with a method of approach that minimizes the technical and financial risk of turbine engines, while at the same time optimizes the safety factors needed to accurately predict component failures. This proposed system is detailed in this report. Appendix A contains the abstracts from the literature search.

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LIST OF ABBREVIATIONS AND SYMBOLS

AI	Artificial Intelligence
ATE	Automatic Test Equipment
ATF	Advanced Tactical Fighter
BITE	Built In Test Equipment
CRT	Cathode Ray Tube
DECU	Digital Engine Control Unit
DIALOG	Dialog Information Services, Inc.
ECM	Electronic Counter Measures
EDS	Engine Diagnostic System
ED&T	Engine Diagnostics and Trending
EMS	Engine Monitoring System
FAA	Federal Aviation Administration
FDR	Flight Data Recorder
HUD	Head Up Display
HUM	Health and Usage Monitoring
ITEMS	Integrated Turbine Engine Monitoring System
LAN	Local Area Network
NTIS	National Technical Information System
OCM	On Condition Maintenance
OCR	Optical Card Reader
QDM	Quantitive Debris Monitor
RF	Radio Frequency
SBIR	Small Business Innovation Research
SCT	Systems Control Technology, Inc.
SSME	Space Shuttle Main Engine
TED	Turbine Engine Diagnostics
TEMS	Turbine Engine Monitoring System

EXECUTIVE SUMMARY

This report presents the results of a system study for the Turbine Engine Diagnostics (TED) program. This research project was initiated to develop a method of approach and a prototype design for a system capable of predicting the failure of rotating parts in turbine engines. Systems Control Technology (SCT) Inc. was contracted by the Federal Aviation Administration (FAA) and used an innovative approach that assimilated data from multiple sources for determining trends in engine performance and health. SCT initially performed an extensive technical literature search and industry survey to augment the present understanding of current technology in the industry for computerized diagnostic systems and measurement sensor technology. The result of this study is a proposed system with a method of approach that minimizes the technical and financial risk of turbine engines, while at the same time optimizes the safety factors needed to accurately predict component failures. This proposed system is detailed in this report. Appendix A contains the abstracts from the literature search.

1. INTRODUCTION

This System Study details the work performed under the Turbine Engine Diagnostics (TED) program. For some of the information on technical literature and industry systems, the study drew upon data gathered in the Final Report for the Health and Usage Monitoring Systems (HUMS) Certification Requirements project produced by SCT for the Federal Aviation Administration (FAA) (contract no. DTFA01-87-C-00014). Since the HUMS effort categorized several different types of health and usage monitoring systems, including those for turbine engines, this data is very relevant to the TED program.

The technical effort for the TED program was divided into the following areas:

a. A literature search identifying and categorizing the multitude of turbine engine monitoring systems that are presently in service;

b. An analysis of the literature search for development of a prototype system concept;

c. References from the HUMS industry questionnaire for additional information;

d. Identification and categorization of systems identified; and

e. Development of a methodology and a system concept for a turbine engine rotor monitoring system.

The TED program builds upon many years of work in the field of engine diagnostics (Section 2). The technical objectives (Section 3) of the TED system have been defined. The results of the literature search and the industry survey (Section 4) are followed by the TED system concept, including a detailed discussion of design issues (Section 5), and our conclusions are presented in Section 6.

Appendix A contains the abstracts from the literature search.

2. BACKGROUND

Gas turbine engine malfunctions, specifically uncontained rotating component failure, result in one of the most catastrophic of all in-flight emergencies. This type of in-flight failure jeopardizes countless human lives and can result in the complete loss of aircraft, crew, and passengers. A similar failure on the ground or on non-aircraft applications such as marine and commercial power generating equipment has potentially the same risk of material and equipment loss, but with a reduced probability of human fatalities. There are two courses of action that can be taken to minimize the cost associated with failures of this nature. The first is to predict the failure and take preventative maintenance action. The second course is to contain and deflect the rotating components should a failure occur.

The primary goal of this FAA Small Business Innovation Research (SBIR) Phase I study was to develop a design methodology and a high-level system concept for an integrated diagnostic system that is capable of predicting failure in turbine engines. The system's effectiveness will be judged by its ability to minimize cost while maximizing safety.

The proposed design has specifically addressed the functional requirements of the following:

a. Operator/Pilot;
b. First line Maintenance Technician; and
c. Overhaul/Depot level mechanic/technician.

The ability to accurately collect detailed operational parametric data on turbine engines is fundamental to assessing the condition, and/or the health of the engine, and ultimately to predict impending failure of rotating components. The introduction of digital engine controls in the 1970s, coupled with increases in computer processing speed and storage capacity, has significantly enhanced the capability to monitor engine and aircraft performance. Recent technological advances in sensor capability permit us to measure and record operating parameters of the aircraft, the engine, and it's operating environment. This recorded information can now provide the ability for predictive maintenance.

A significant amount of money is spent each year performing corrective maintenance on turbine engines that have either experienced a hard failure or have undergone troubleshooting procedures in response to operator reported malfunctions. When unscheduled maintenance is performed it is usually at inopportune times, with little foresight and consequently with no planning for the material or manpower resources to perform the maintenance action. The

operational impact in many cases is the greatest cost. The operational cost, often not measured in dollars and cents, is usually couched in terms of lost passenger miles, disrupted or delayed schedules and customer dissatisfaction. Management efforts to reduce the maintenance and operational costs often center on redundant components, expensive work-around systems for expediting the maintenance, and contingency plans to increase production capacity. This is all at the cost of expensive overtime. Along with researching the design of a predictive system, the study has considered the benefits improved maintenance procedures will have with the use of any of the recommended predictive tools.

3. PHASE I TECHNICAL OBJECTIVES

The short term objective of this Phase I effort was to increase our current understanding of the diagnostic systems that are being developed today throughout the commercial industry and to provide a comprehensive description of the technology being developed for failure prediction and prevention. This has been accomplished and the results of the literature search and the industry survey follow in Section 4.

The major objective of this Phase I effort was to develop a cost effective and technologically sound system concept for an integrated predictive diagnostic and trending system. By achieving the goal of Phase I, the risk associated with a Phase II SBIR effort to build a prototype system utilizing modern technology for failure prediction is greatly reduced. Figure 3-1 is a high level overview of the various systems that must be integrated to provide accurate failure predictions. This figure illustrates the complexity associated with the goal of this program.

The Phase I effort has addressed the feasibility of the proposed design for supporting the kinds of actions listed below and depicted in Figure 3-1.

a. Vibration Analysis;
b. Parameter Engine Monitoring;
c. Non-Destructive Inspection;
d. Critical Life Usage;
e. Oil Analysis Debris Monitoring;
f. Maintenance Actions; and
g. Operating Environment.

Specific methods and output devices would be addressed in detail during the Phase II prototype development. The rapid advances in computer technology and output devices significantly influence the type of devices that are used to advise operators of actual and impending turbine engine's component failures. Future output devices might range from warning lights, reconfigurable Cathode Ray Tube (CRT) displays, Head Up Displays (HUD), and voice warning to some degree of automatic control over the operation of the engine. One of the goals of the Phase II effort would be to investigate the feasibility, practicability and availability of future output devices.

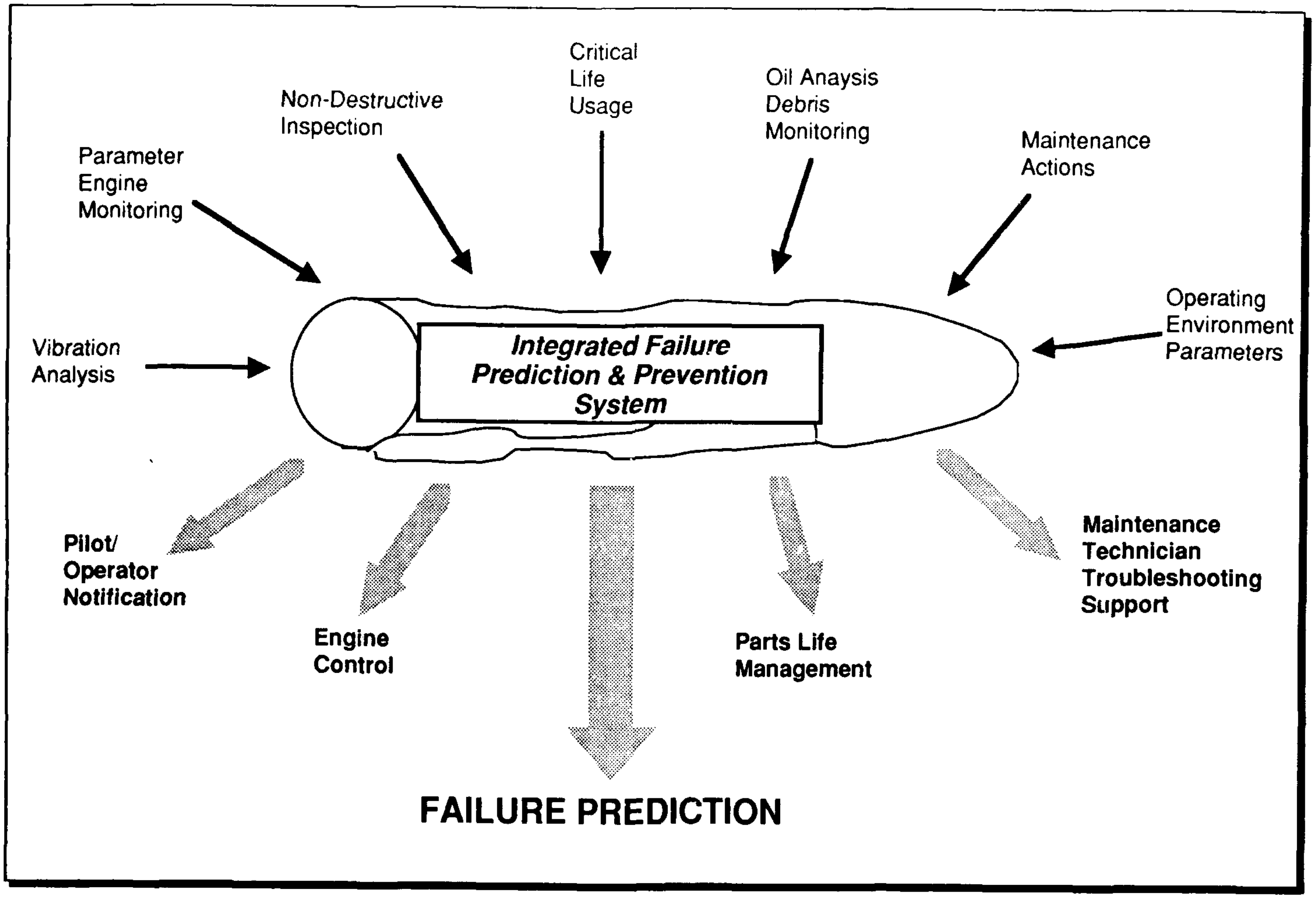


FIGURE 3-1 System Overview Of An Integrated Failure Prediction System

The majority of existing diagnostic system designs have focused on specific requirements in only one of these functional areas. Our innovative approach addressed the design from a totally integrated approach. We have combined the requirements of the pilot/operator, first line maintenance technician and the overhaul/engineer into a single design. The data from multiple sources has been integrated into a single processor capable of assimilating the data and predicting possible failures based on a comprehensive picture of the engine condition and its operating environment. The hardware environment developed for this system will support all of these requirements in a building block approach and provide the necessary information at each of the three levels.

4. SYSTEM SURVEY

4.1 LITERATURE SEARCH

This section describes the literature search and the industry survey that was conducted under the Phase 1 SBIR for Turbine Engine Diagnostics. The overall goal of this information was to assist in developing a methodology and a prototype design for a system capable of predicting failure of rotating parts in turbine engines. The effort was divided into the following areas:

a. A literature search identifying and categorizing the multitude of turbine engine monitoring systems that are presently in service;

b. An analysis of the literature search for the development of a prototype system concept;

c. An industry questionnaire for additional information; and

d. An analysis of the industry responses in order to identify and categorize systems.

4.1.1 Purpose of the Literature Search

The purpose of the literature search was to gather technical literature on turbine engine diagnostics technology. The search has concentrated on both military and civilian efforts in the development of automatic systems that monitor the performance and calculation of the state of health for turbine engine systems. The ultimate goal is to provide the information necessary to develop a system that is capable of predicting failures in turbine engines.

4.1.2 Technical Approach of the Literature Search

The engineering staff conducted an exhaustive literature search of military and civilian libraries to expand our current knowledge base and determine which firms are involved in areas such as parts tracking systems, diagnostics systems, health monitoring systems, performance trending systems, sensors, software development and expert system technology. We used the resources of SCT's account on NTIS and performed computer assisted searches using key words in context approach to locate abstracts on technical

papers describing these systems. We analyzed the abstracts to determine which documents should be reviewed in their entirety for the effort. These documents were ordered and reviewed in detail. Appendix A contains the total abstracts gathered under the survey. These documents were reviewed in detail.

4.1.3 Data Sources

The data sources included the following:

a. National Technical Information Service (NTIS);
b. SCT technical library;
c. DIALOG; and
d. Trade journals on health usage and monitoring systems.

The majority of the systems that we reviewed addressed engine monitoring or engine and drive-train monitoring. We found very few papers that addressed integrated diagnostics from the point of view of monitoring and diagnosing total air-vehicle performance or health. Most systems monitored only a single parametric function such as vibration, oil analysis, engine health, etc.

We did not limit the selection of documents to only turbine engine systems because of the significant amount of work that has been accomplished in fixed wing aircraft diagnostic systems as well as air-breathing and rocket engine systems.

In particular, there is a wealth of information on diagnostic systems within the Space Shuttle Main Engine (SSME) development effort. The Space Shuttle Main engine is the first operational liquid rocket engine developed for reuse. Because of the potential for catastrophic consequences associated with a failure during ground testing and during in-flight operation, there has been considerable emphasis on the development of quite sophisticated monitoring systems. Therefore, several documents are included that report on efforts in this area.

The increased application of Artificial Intelligence technology, in particular the use of expert systems, shows considerable promise as new monitoring and diagnostic applications are developed. Several of the articles that were reviewed predict that artificial intelligence has the potential to deliver significant advances in productivity and accuracy in monitoring systems.

4.1.4 Search Methods

In addition to manual library searches and review of periodicals and trade journals, we have made use of automated library searches. These automated services facilitate the search of large data bases using a common set of key words and phrases. Two major services were used; The National Technical Information Service (NTIS) and DIALOG. Numerous commercial publications such as Rotorcraft Magazine, Avionics Magazine, Aviation Equipment Maintenance Magazine, Aerospace Engineering and the 1990 Helicopter Annual were also used.

Over 1000 abstracts were reviewed on the NTIS and DIALOG systems using a combination of keywords from the following list:

EMS	Health Monitoring	Expert Systems
EDS	Condition Monitoring	Diagnostic Systems
HUM	Usage Monitoring	Engine Trending
OCM	Engine Monitoring	Helicopter
FDR	Integrated Diagnostics	Rotorcraft
TEMS	Diagnostics	Prognostics
ITEMS	Trending	

In addition to the selected keywords, the computer search was often refined by limiting the documents to USA published documents or documents published later than 1985. Without narrowing the search, we were often presented with thousands of documents to review, many of which had little relationship to the desired subject.

4.1.5 Document Retrieval

We narrowed down the document selection to more than 90 documents which are catalogued in Appendix A. In this index, there is an abstract for each document. Document sources will include the NTIS library, the American Institute of Aeronautics and Astronautics library, as well as papers, commercial publications and trade journals which are currently maintained by the SCT technical library.

Many of the documents contain information on more than one aspect of monitoring systems or address more that one area. For ease of review, the documents have been divided into the following five subject categories:

a. Aircraft Diagnostics (Section 1);
b. Helicopter Diagnostics (Section 2);
c. Rocket Engine Diagnostics (Section 3);
d. Technology (Section 4); and
e. General (Section 5).

Each document is given a identifying number which gives the sequence number within the section, a three-letter code identifying the category, a sequence number within the entire number of documents, and finally the letters "SCT-TED" to identify the company and project responsible for the compilation of these documents.

4.2 INDUSTRY SURVEY

The purpose of the industry survey was to determine which industrial firms are participating in the development of turbine engine diagnostics systems.

4.2.1 Technical Approach of Survey

The list of firms developed from the literature survey was used as the initial source of locating industrial sources. We compiled a questionnaire on the relevant issues surrounding turbine engine diagnostics systems. The questionnaire results were analyzed and compiled. As additional sources are uncovered they were contacted directly and a questionnaire was sent for them to complete.

4.2.2 Data Sources

The data sources used consisted of industrial firms participating in the development of turbine engine diagnostics systems.

Commercial and military contractor information expanded the current knowledge base in order to help determine which firms are involved in areas such as parts tracking, performance trending systems, health monitoring systems, diagnostic systems, sensors, software development and expert system

technology. The survey was also a forum to address user comments and include them in our evaluation of the technology. These comments were used in the consideration and preparation of the system concept. A summary of the results is presented in Figure 4-1.

4.2.3 Identification/Categorization of Systems

Systems were identified and categorized which are relevant to this effort. In many of the technology areas, aspects of each system has particular relevance to the system concept. What this effort reflects is the synthesis and evaluation of relevant technology areas. Within the identification process, existing and developing health monitoring and diagnostic systems have been identified and categorized according to manufacturer, function, aircraft type, propulsion type, number of engines, etc. The technology cited in the industry survey was carefully examined with respect to types of sensors, monitoring technologies, and processing capabilities. Figure 4-2 highlights the published papers which have been selected from the survey for their direct relevance to the system concept.

4.3 TECHNOLOGY ASSESSMENT

Advances in the areas of avionics, propulsion, sensors and computer technology have had significant impact on the development of turbine engine diagnostics systems. We have come a long way from hanging analog reading devices on aircraft and systems and copying down data for later analysis. New sensor technology has made use of fiber optics, micro-miniature components, strain gages and laser technology common place in collecting data. Improvements in cooling, shock mounting and rugged packaging have permitted placing sensors and processors in previously inaccessible places on the aircraft. Perhaps the most significant advances have been in the speed of processors and the increase in on-board data storage. The combination of all of these factors have facilitated in-situ capture, processing and recording of diagnostic data. The operational impact ranges from the in-flight collection of data for ground processing, to immediate pilot notification of subsystem performance and in the ultimate case to actual control of a subsystem base on real time analysis.

The use of Artificial Intelligence techniques, particularly expert systems, will continue to expand in both the airborne and ground diagnostic systems. Several of the new technologies are discussed in the following paragraphs to give the reader an idea of what is taking place as one considers the certification of new diagnostic and monitoring systems.

		Type				Function					System			Subject System				Sensors					Aircraft Subsystems								Monitor. Tech.			Processing Capab.	
Manufacturer	Program	Fixed Wing	Rotorcraft	Marine	Power Generation	Parts Life Tracking	Diagnostics	Trending	Failure Prediction	Operating Performance	Health	Usage	Diagnostic	Conceptual	Development	Production	Operational	Propulsion	Airframe	Flight Control	Avionics	Other	Mechanical	Electrical	Vibration	Oil Monitoring	Accelerometers	Temperature	Optical	Liquid Level	Realtime	Continuous	Periodic	Realtime	Batch
VIBRO-MATIC, LTD.	ROTABS		•				•			•	•				•		•	•	•						•		•				•			•	•
TELEDYNE-AVIONICS	PAR	•	•				•		•	•	•	•	•			•	•	•				•	•	•				•			•	•		•	•
SIKORSKY	EEMS,AVIDS,IFIP,HELIX		•			•			•		•	•	•		•	•		•	•	•	•	•	•	•		•					•	•		•	•
MIL-COM ELECTRONICS	EFDS	•					•	•			•	•	•		•	•	•	•	•				•	•				•			•	•	•	•	•
CMC	CMA-2055		•					•		•															•							•	•	•	•
BELL	VSLED		•			•	•	•		•	•	•	•		•	•		•	•						•			•			•			•	•
AMETEK	EMSC	•	•			•	•	•		•			•				•				•			•					•	•	•	•		•	•
CHADWICK HELMUTH		•	•								•	•	•		•	•	•	•	•			•			•		•					•		•	•
POWER MANAGEMENT SYSTEMS	PMS 8000-7									•													•	•				•			•	•		•	•
SEMCO		•	•	•	•						•	•					•	•				•													
KEYSTONE HELICOPTERS	EPRS,IMADS	•	•					•		•	•	•	•		•	•	•	•	•			•			•			•			•	•	•	•	•
HOWELL INSTRUMENTS	EPAMS,PEATS	•	•			•	•		•		•	•	•				•	•							•			•			•	•		•	•
BRISTOW HELICOPTER, LTD	HUMS		•				•				•	•	•			•		•	•						•	•									

FIGURE 4-1 Survey Results

SYSTEM	MFG	Helicopter H / FW Fixed Wing	TYPE A/C	M/D Monitoring Diagnostic Type	Airborne / Ground	AI/EXPERT (Y/N)	FAA Approved (Y/N)	MATURITY			Remarks
								Concept	Dev	Opera-tional	
1. EPAMS	Howell Inst	H/FW	Various	M	A	N	Y			√	Usage and exceedance monitoring,optional vibration monitor
2. H/PESA	Honeywell	H	Various	M/D	A	Y	N	√			Emergency advisory system
3. HELIX	Sikorsky	H	TBD	M/D	A	Y	N		√		Diagnoses engine failures
4. IFIP	Sikorsky	H	TBD	M/D	G	Y	N		√		Follow-on to Helix, maintenance oriented
5. AIMS/IHUMS	Plessey/BHL	H	TBD	M/D	A	N	N		√		Joint effort for CAA requirements
6. PAR	Teledyne	H/FW	Various	M/D	A	N	Y			√	Power assurance checks, exceedance and usage monitoring
7. ROTABS	Vibro-Meter	H		M/D	A/G	-	N			√	Rotor track and balance, maintenance instructions
8. COMPASS	RR/SD-Scicon	FW		M/D	G	N	N			√	In use with Lufthansa, British Airways and TWA
9. XMAN	SCT	FW	Various	M/D	G	Y	N			√	PC-based maintenance/diagnostic tool, military engines
10. AAM/OA	Bell	H/FW	---	M/D	---	--	N	√			Maintenance and diagnostic design criteria for future military avionics
11. ETADS	Bell	---	---	M/D	---	--	N		√		Engineering development tool
12. IMETS	Bell	H/FW	TBD	D	G	N	N	√			R&D, PC-based maintenance/training
13. VSLED	Bell	H	V22	M/D	A	N	N		√		Vibration, structural, life, and engine monitoring for V-22 Osprey
14. LH ID	Bell	H	LH	D	A	N	N		√		Integrated diagnostics for LH helicopter
15. GIMADS	GD/Bell	H/FW	Various	M/D	G	TBD	N	√			Integrated diagnostics program aimed at developing mil-standards for USAF
16. TRENDKEY	Keystone Hel	H	Various	M	A	N	Y			√	Measures exceedance & fuel mgmt., systems monitor, air data computer, lower cost market
17. TMS	Safe Flight Instruments	FW	Various	N	A	N	N			√	Thrust management system
18. EMSC	Ametek Douglas	FW	F-16	M/D	A	N	N			√	Exceedance monitoring and fault isolation
19. CADS	Gadzala	H	---	D	G	Y	N	√			Lcdr Gadzala Naval Post Graduate School
20. EDS	McDonnell Douglas	H	AH-64A	M/D	A/G	--	N		√		Structural monitoring, operation loads data

FIGURE 4-2 Identification/Categorization Of Applicable Systems

4.3.1 Integrated Diagnostics

Historically, diagnosis of electrical, mechanical and propulsion subsystems has been accomplished at the subsystem level, and only for that subsystem. That kind of approach has naturally led to the proliferation of different type of diagnostic systems and, often, duplication of effort. The avionics subsystems were the first to integrate diagnostic functions among the various avionic subsystems such as Communications, navigation, Weapons delivery, ECM, etc. The results of avionics diagnostics were presented on Avionics status panels and later as the data bus concept developed the information was recorded and analyzed in on-board processors. With the advent of integrated flight controls, Digital Engine Electronic Controls, and fly-by-wire aircraft such as the F-16, all of the diagnostic information has become available on a common data bus. An integrated approach to diagnostics implies that each of the aircraft subsystems generate critical information that is important not only to the pilot, but to the maintainers of the aircraft. New aircraft such as the ATF and the Stealth Bomber recognize that diagnostics are a function that envelopes the entire aircraft and are developing turbine engine diagnostics systems in that light.

Aircraft now in the design and development cycle will address diagnostics from a systems approach. The challenge is integrating diagnostics on existing aircraft. That is perhaps beyond the scope of this study, but the technology associated with integrated diagnostics will surely need to be addressed in the certification process for new diagnostic systems.

4.3.2 Artificial Intelligence

A new interest in engine monitoring is the use of one aspect of Artificial Intelligence, Expert Systems. As mentioned in the above paragraph, the use of a computer diagnosing trouble in avionics systems is well established. The use of Automatic Test Equipment (ATE) and Built In Test Equipment (BITE) is wide spread throughout the avionics systems. The use of Expert systems involves capturing the "Expert" knowledge of human engineers and troubleshooters and committing that knowledge to a set of rules that can be quantified and stored in the computer. The rules must emulate the knowledge of a wide range of human experts and function with the speed of todays modern computers. The expert system receives data from the sensors on an aircraft or subsystem, stores data, converts the data to knowledge, or facts, describing the condition the subsystem and applies the rules of the expert to determine or recommend an action. Most of todays expert systems applications keep the human "Expert" in the loop. As expert systems continue to be developed and gain confidence, their use will rapidly expand to all areas of diagnostics and maintenance. The particular advantage of these systems is their ability to absorb vast amounts of input facts

and make a consistently accurate decision in a split second. It is our opinion that AI technology, most notably the use of expert systems will play an increasing role in the development of turbine engine diagnostics systems.

4.3.3 Debris Monitoring

The role played by particulate analysis of lubricating fluids in engines has been limited in the past to analyzing the oil, on the ground after the fact. The oil analysis results were normally used in conjunction with other indicators to assess the condition of mechanical systems. Recent developments allow, for the first time, microprocessor-based on-board systems to detect and collect significant data during system operation. While the role of Quantitative Debris Monitoring (QDM) remains essentially the same, the speed and accuracy at which it can be accomplished permits the correlation of seemingly unrelated symptoms to confirm an impending or actual failure. The reliance on real-time debris monitoring technology as an input to integrated diagnostic systems will also increase as new aircraft systems are designed.

4.3.4 Vibration Analysis

As with debris monitoring technology, the improvements in sensors and on-board processing capability provide one more source of data for the diagnostic systems. In the area of vibration, digital processing can precisely measure engine, drive-train, and accessory vibration. Previous analog systems with one or more fixed data bands were subject to uncertainty as to whether the data was real or a false alarm. Digital systems virtually eliminate that ambiguity. Structural Integrity programs will surely benefit from the results of improvements in this area of technology. The benefits of inputting this type of data into the integrated diagnostics systems will include more accurate ordering of spare parts, more operational spare engines and a reduced number of spares. As an additional data input to a diagnostic system, vibration monitoring information will support the on-condition maintenance concept. This type of information will certainly reduce the number of catastrophic failures and the resultant damage associated with secondary failures.

5. PROTOTYPE METHODOLOGY AND DESIGN

During the course of this effort, the functional requirements of airborne and ground systems were carefully analyzed. The proposed design is capable of satisfying the predictive and preventative goals listed below:

a. Fault Detection and Correction;
b. Data History Recording;
c. Performance Trending;
d. Prognosis - Failure Detection;
e. Recommended Maintenance Actions; and
f. Configuration Management.

The design provides a diagnostics capability for both in-flight and ground operation. Figure 5-1 depicts the primary prototype design functions that must be satisfied by an integrated engine failure prediction system.

Data that is available from the engine control, i.e., Digital Engine Control Unit (DECU), can support parts life usage tracking and engine health monitoring. Although the two functions are related from a data collection point of view, we have distinguished between usage monitoring and health monitoring. The former is the measure of accumulated life on selected components, and the latter is the prediction of the probability of a failure within a given time period. The emphasis has been on health monitoring and predictive techniques.

Artificial Intelligence, particularly expert systems technology, was investigated as a means to reduce the complexity of data, isolate the important and relevant data parameters and recommend an immediate course of action in a dynamic mode to the pilot and in an after the fact mode to the maintenance technician/analyst. The operator of the system (i.e., Pilot or Maintenance Technician) must remain an integral part of the decision making process.

The monitoring techniques for fixed wing aircraft are significantly different from those for rotorcraft for a number of reasons. These reasons include:

a. Weight limitations on helicopters;
b. Failure modes;
c. Rotor tracking; and
d. Vibration requirements.

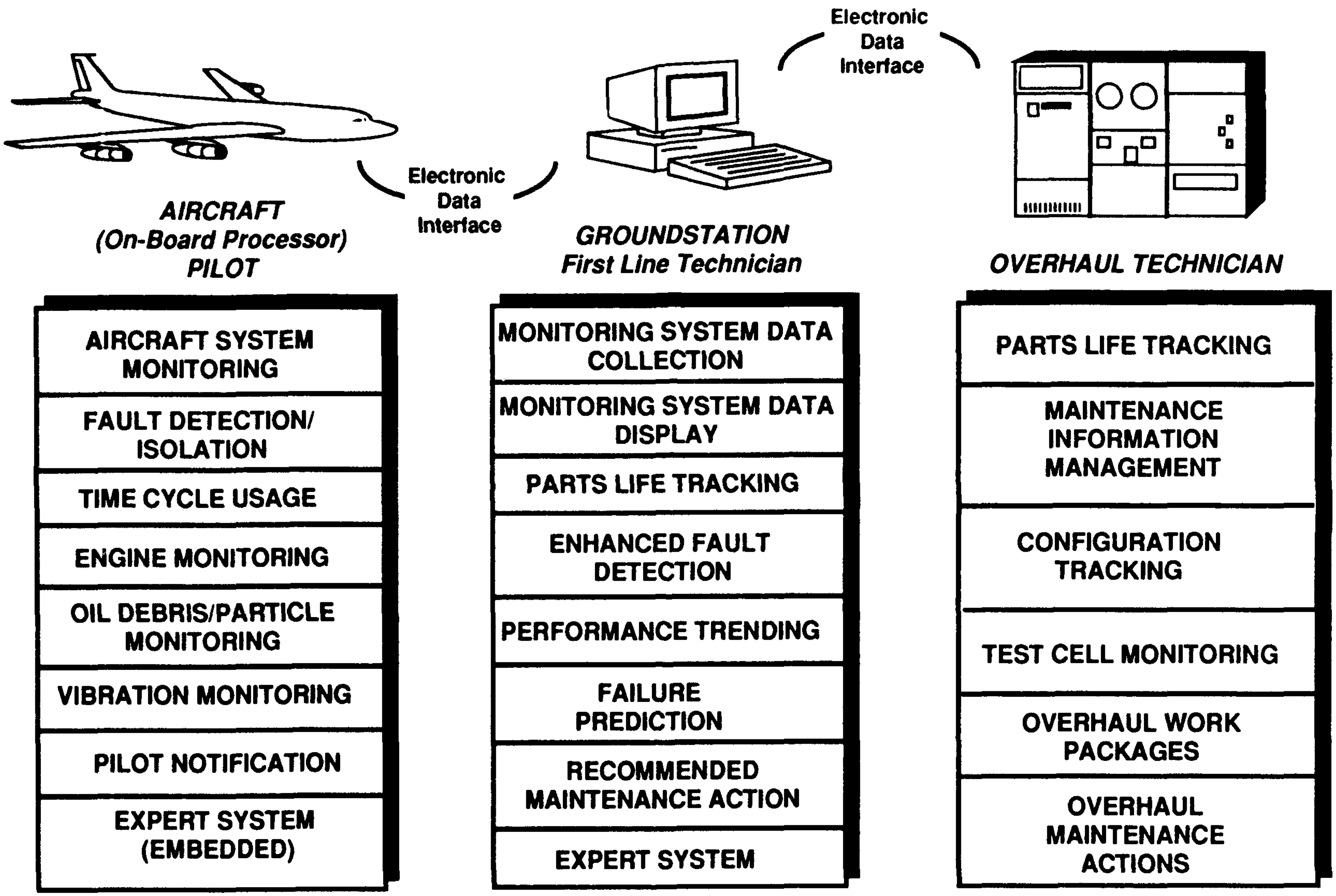


FIGURE 5-1 Prototype Functional Design

These differences influence the design of a totally integrated diagnostic system. It is not unreasonable to suggest that there might be a different design for an integrated diagnostic system for fixed wing and rotorcraft. As the rotorcraft fleet continues to grow, both the military and FAA requirements for a diagnostic system continue to play a greater role. These issues have been addressed during the course of the research.

The final product of the Phase I effort is a high level system concept for an integrated diagnostic system capable of predicting the failure of rotating turbine components. The following sub-sections discuss in detail the prototype methodology and system concept.

5.1 PHILOSOPHY

Several elements are inherent to an effective engine failure prevention and prediction system. These elements are as follows:

a The system must utilize consistent application of a variety of diagnostic methods;

b All information available to the system must be fully integrated;

c. The system must present data formatted and displayed in the most appropriate manner for the maintenance and operational personnel depending on their function;

d. The system must be capable of monitoring the maintenance action effectiveness through the correlation of the maintenance database with performance data; and

e The system must monitor maintenance actions with regard to safety.

5.2 SYSTEM CONCEPT

5.2.1 Overall System Concept

The heart of the proposed TED system, as depicted in Figure 5-2, is the Historical database.

The historical database is fed from a variety of sources, as detailed later in this section. Some or all of the elements of the algorithm toolbox (Figure 5-3) will be employed in the final TED system. The choice of elements to be utilized is heavily dependant upon the specific application of the system For example, aircraft operated by a large airline are likely to have a majority of the algorithm toolbox elements in place, while a smaller airline would most likely have a very limited subset of these elements.

Data management will serve to ensure that data is validated and stored in such a manner as to be of maximal use to the maintenance and operations personnel employing the TED system. The specific data management functions are addressed in Section 5.3.1.

The user interface serves as the bridge between the historical database and then end user. This interface must be designed in such a manner as to present the data in a useful and easily interpreted form to suit the needs of each user. The specific user interface issues are addressed in Section 5.3.3.

A critical element in the functioning of the proposed TED system is the network of computers. The network provides access to the historical database by all users and makes possible deployed operation by maintenance/ operations personnel. For example, the network will support diagnostics at the aircraft, and provide maintenance suggestions to the technician at the maintenance facility. The specific details are addressed in Section 5.3.4.

Based upon research and past experience in engine diagnostics and trending, SCT has developed an overall concept for the Turbine Engine Diagnostics system. The following characterize the attributes of the system:

a. To be most effectively used by maintenance and operational personnel the system must be a portable, yet an integrated tool;

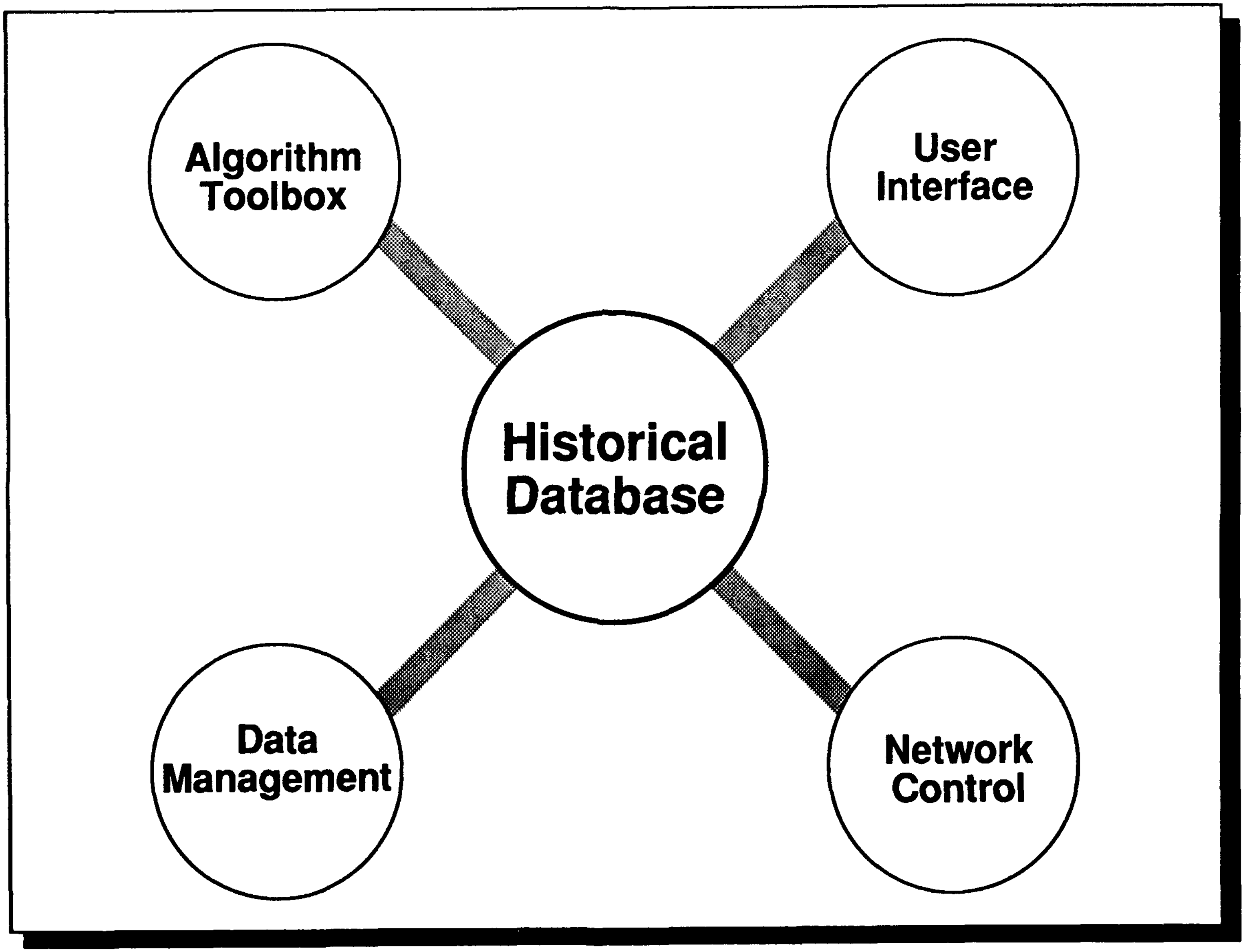


FIGURE 5-2 System Architecture

	PERFORMANCE ANALYSIS	OIL MONITORING	VISUAL INSPECTION/ NDI	CONDITIONAL INSPECTION/ REPLACEMENT (LIFE USAGE MONITORING)	VIBRATION MONITORING
PARAMETERS	• Cockpit Instruments • Engine Mounted Sensors • Airframe Sensors • Switches/Discretes	• Contamination Level/Element • Oil Type, Oil Added/ Change • Particle/Debris Size • Cummulative Wearmetal Levels • Physical Properties	• Narratives • Crack Lenght/Location • Rotor Imbalance • Functional/BITE	• Operating/Flight Time • Time Above Power • Cycles (Landing, Power, etc.)	• Hard Mounted Accelerometers • Strain Gauges • Vibration Surveys
METHODS	• Flight Condition/Power Correction • Manufacturer Performance Envelope • Parameter Estimation Models • Aceedance and Forecast	• Level Exceedance - Level/Rate • Unusual Data Signatures • Forecasting • Correlations	• Subjective Evaluation vs. Publish Standards • Crack Length Trending • Dye Penetration, etc.	• Limit Exceedance • Flowdown to Part Indenture • Forecast vs. Flying Schedule • Anamoly Detection (Abnormal Accrual)	• Level Monitoring • Frequency Baud Levels • Signal Processing/ Correlation • Level/Characteristic Trending

FIGURE 5-3 Diagnostic Application Toolbox

b. The system must cover a broad spectrum of inputs and outputs;

c. The system must be flexible enough to adapt to future changes in equipment and diagnostic procedures;

d. The system must be modular in design to facilitate modification;

e. The TED system should utilize a toolbox analysis approach to make optimal use of all available diagnostics data sources; and

f. To make most effective use of this toolbox of data, the system should maximize networking to the extent that it is practical. For example, the system should use Local Area Network (LAN) and Ethernet technology as much as possible. This will speed up access to the historical database etc.

5.2.2 Diagnostic Application/Algorithm Considerations

Contained in Figure 5-3, there is a summary of the potential functions supporting an engine failure prevention and prediction system, including a description of the input parameters as well as the methods to be applied in executing each type of function. Each of the methods detailed in Figure 5-3 raise several issues about the difficulty of implementation. Figure 5-4 summarizes the relative trade-offs between ease of data collection and other design criterion. For example, Visual/Non Destructive Inspections have the advantage of relative ease of data collection, but are prone to substantial time delays in entering the resulting data into the system. It is important to stress that the choice of methods to be applied will vary considerably depending on the needs of the particular application and the availability of the necessary data sources.

5.3 FUNCTIONAL REQUIREMENTS

5.3.1 Data Management

Perhaps the single most important function of the TED system is the management of the myriad of data available to the system. The data

METHODS	APPLICATION ISSUES			
	Data Collection	Algorithm Design	Engine Math Model	Time Delay
Conditional Inspection/ Replacement	B	A-C	---	C
Vibration Monitoring	B	A-B	---	C
Performance Analysis	B-C	B-C	A	B-C
Oil Monitoring	B	C	C	A
Visual/NDI Inspections	B-C	C	C	A-B

A = Difficult
B = Moderate
C = Easy

FIGURE 5-4 Diagnostic Algorithm Issues

management task can be broken down into three categories of data. Each of these is described below:

a. Diagnostics Data. This can include high resolution data captured by the on-board system, facts generated by the expert system troubleshooting aid, and the results of troubleshooting sessions or diagnostic routines;

b. Maintenance Data. This data is comprised of maintenance actions initiated against a particular piece of equipment and the results of post maintenance inspections; and

c. Tech Data. This is the data detailing maintenance and inspection procedures. This data is an integral part of the diagnostic procedures implemented by the expert troubleshooting aid.

The task of data management is to store and integrate the above mentioned data in such a way that it will be of maximum value to the maintenance and operational personnel. Typical data management functions for an engine information management system are detailed in Figure 5-5. All of these functions are anticipated to be incorporated in the TED system.

5.3.2 Data Presentation

The TED system must be capable of presenting the stored data in a manner which most greatly facilitates the performance of the maintenance and diagnostic tasks. The system that we are proposing integrates test and graphics in its displays to convey the relevant information in an effective and easily interpreted form. The format of the screens must be flexible to allow the user to retrieve information in the desired format, i.e. tabular or graphical. The system must be capable of custom delivery of data presented in a format tailored to the needs of the individual users. Data presentation, when developed correctly, insures that each user has access to the relevant data in the format most compatible with their function and needs.

5.3.3 User Interface

Through its extensive development of fielded information management systems, SCT has compiled a great deal of knowledge about the most effective user interfaces. If the user is put off by the complexity of the system or becomes

- **Relational Database**
  - Performance
  - Vibration
  - Oil Analysis
  - Time Cycle
  - Diagnostics
  - Maintenance History
  - Configuration

  Related/Linked Tables
- **Limit Detection**
- **Management-By-Exception/Alarms**
- **Forecasting/Prediction**
- **Pattern Recognition/Neural Network**
- **Maintenance Correlation**
- **Data Correlation**
- **Expert System Procedures**

FIGURE 5-5 Generic Data Management Functions

confused while operating the system, the system will not be utilized to its full potential. Indeed, in the extreme, the system may even fall into disuse if the interface is sufficiently unfriendly and complicated to the user.

Due to the demands of the operational environment (weather, location, etc.) the most effective means of interaction between the user and the system is via a touchscreen. The less information that the user has to enter, the lower the chance of data transcription errors, and the higher the system effectiveness. Touchscreen capability allows the user to select the desired answer or function by touching a portion of the computer screen. This capability is particularly useful in a harsh environment where the operator may have to be wearing cumbersome protective clothing.

Finally, in order to reduce the learning curve and to lessen user frustration, the system must be self training to the extent practical. The primary method of achieving this is through extensive context-sensitive help screen that will provide the user with in-depth explanations of the function currently being executed.

5.3.4 Network Design

To maximize the integration of the data in the TED system we are proposing a network design featuring both portable maintenance aids and desktop workstations. The specific operational concepts are discussed in section 6. A general network system overview is depicted in Figure 5-6. The network design features portable maintenance aids and a workstation communicating via a Radio Frequency (RF) Link. The technology exists for such a system and SCT is currently gathering information from manufacturers. It is envisaged that the workstation could communicate with a mainframe serving as the repository for the historical data. This would require a high speed communications link, such as a LAN, based on Ethernet technology.

5.3.5 Data Interface

To support the TED system, a number of data interfaces must be developed. These interfaces are discussed below:

a. Manual Input. The system must be capable of accepting data from manual sources. Possible sources include, but are not limited to, data recorded by the flight crew, i.e. instrument readings at cruise, performance discrepancies

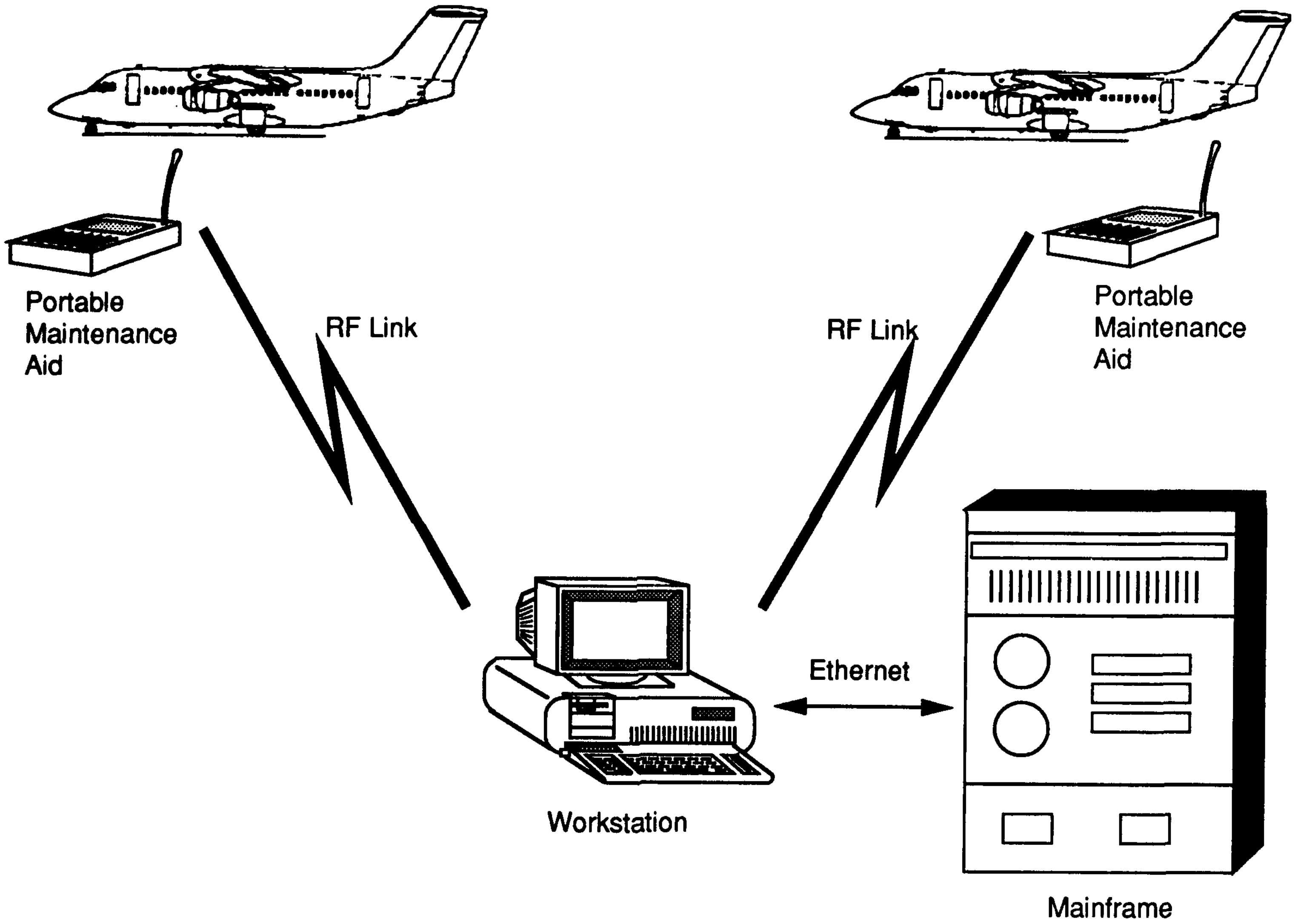


FIGURE 5-6 General Network System Overview

noted by the crew or maintenance personnel, and special comments attached to a particular discrepancy or maintenance action;

b. Flight Data Recorder. The preferred method of obtaining performance and diagnostics data for the system is via the flight data recorder. As discussed previously, to the degree that data gathering and transfer is automated, the number of data transcription errors in the system will drop correspondingly;

c. OCR. The purpose of this interface is to provide a means of automatic data entry via the use of an optical card reader to scan flight sheets;

d. Barcode. Barcoding can be used to log such information as engine number and part numbers. The advantage of barcoding is the greatly reduced chance of data transcription errors and the speed of data entry;

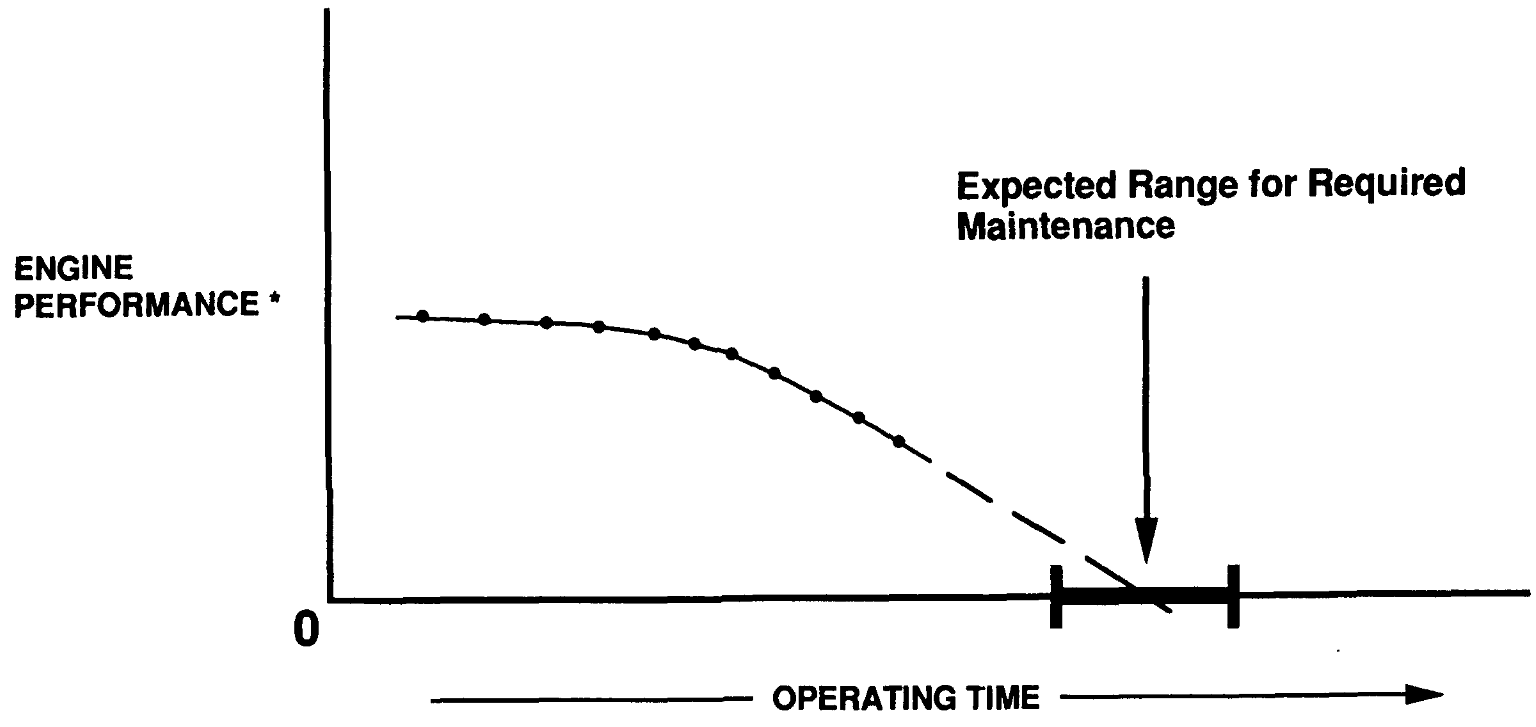
e. Form. One potential application of data forms is in the area of oil wearmetal analysis results. Again, reading the data directly of the form greatly reduces data transcription errors; and

f. ACARS. Many aircraft support the use of the ACARS to download data captured in flight via telemetry. This information can be put to good use by the TED system to perform initial evaluation/ diagnostics, and to see that the necessary resources are available when the aircraft lands.

5.4 EXAMPLES OF DATA MANAGEMENT FUNCTIONS

In this report, we are providing examples of several different data management functions which have proven useful in performing engine diagnostics and trending functions. These examples have been gathered from our experience and from the results of the literature search and industry survey.

The first essential function is performance prediction and extrapolation. A generic example of this function is provided by Figure 5-7. Under performance prediction, engine performance parameters are trended against operating time to predict when predefined performance limits will be violated.



* *Margin to Red Line, Ambient Temperature Moving in, etc.*

FIGURE 5-7 Performance Prediction

This function provides two distinct advantages:

a. Performance prediction allows the scheduling of upcoming maintenance actions, thereby improving efficiency and reducing maintenance costs; and

b. Performance prediction can assist in detecting incipient failures before secondary engine damage has occurred. This in turn can be expected to reduce maintenance action duration and cost of maintenance.

It is important to note that performance prediction can only be effectively employed when engine performance parameters are routinely recorded under similar operating conditions during each flight.

Maintenance correlation can be a very useful tool in evaluating the health of an engine. Maintenance actions may have a big impact on both engine performance and the evaluation of performance trends. Many times a change in engine performance can be explained by recent maintenance actions. For example, if engine oil usage increases dramatically after an oil change action it is reasonable to suspect that there may be an oil leak caused by improper/incomplete maintenance. Clearly, maintenance personnel can benefit from being informed of both the engine performance data and any maintenance actions that have occurred during the period being evaluated. A sample maintenance correlation is depicted in Figure 5-8. Maintenance correlation is also important when utilizing the performance trend function. The system needs to take into account significant maintenance actions when evaluating performance trends. For example, it is not valid to trend oil debris readings across an oil change. Another example of this principal is the water wash maintenance action for the TF-34 engine. The TF-34 is mounted on the A-10 aircraft. When the aircraft fires its nose cannon, gun gas is ingested by the rear mounted engines and coats the turbine blades. A build up of this material on the blades results in a noticeable decrease in performance. Upon spraying the engine with a water hose, engine performance is greatly increased. In cases like these, the engine performance trend must be restarted to accurately track future problems.

Perhaps the greatest contribution that an expert system can make to an engine diagnostic and trending (ED&T) system is in the area of pattern recognition. Figure 5-9 contains examples of possible data correlations leading to a specific diagnosis. In this example, gearbox vibration level readings, oil analysis wearmetal trends, and engine performance trends are evaluated by the expert system to identify suspected core damage. Over time, the system learns how to correlate particular patterns of data with a known engine problem.

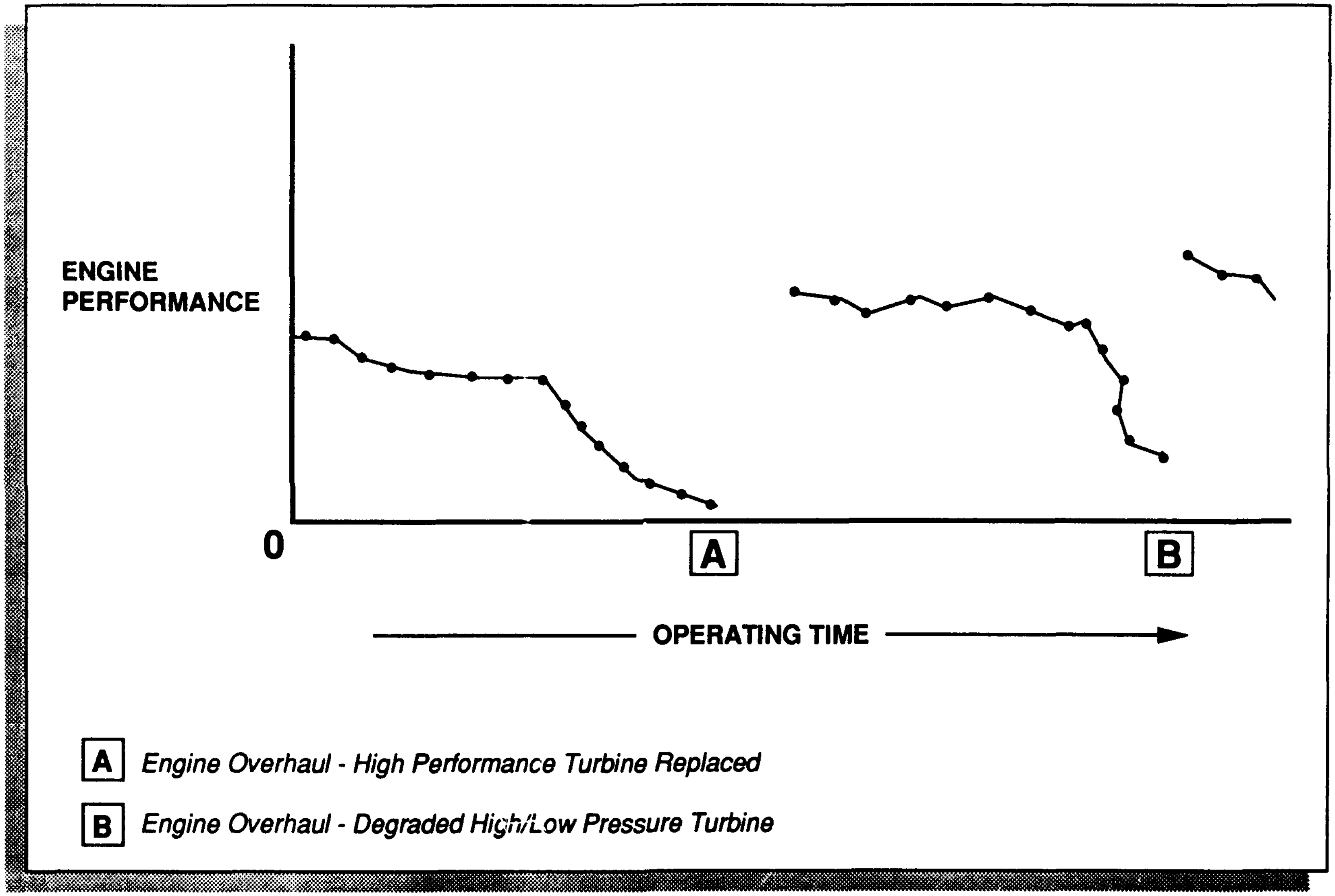


FIGURE 5-8 Maintenance Correlation

As the engine matures, this pattern recognition will become increasingly more accurate. Pattern recognition can greatly assist the engine manager by providing a suggested problem before the problem manifests itself in more extreme ways. In the example depicted in Figure 5-9, the compressor rub can be corrected before a catastrophic event, such as an uncontained engine failure can occur. As with the prediction function, pattern recognition should reduce maintenance costs and increase engine availability and safety.

5.5 SYSTEM CONFIGURATION

The proposed TED system is divided between a desktop workstation and one or more portable maintenance aids/diagnostic tools. As discussed previously, these would be networked together to provide the maintenance/ operational personnel with all relevant information on the desired engine. The specific functions to be performed on the workstation and the portable maintenance aid(s)/diagnostic tool(s), are detailed below.

5.5.1 Workstation

The functions of the workstation can be divided into three basic groups; historical database, technical data management, and mainframe interface. The historical database would be the repository for engine configuration data, diagnostic results, and maintenance reports. Additionally performance trending would be performed using the data contained in the historical database.

The workstation would also provide the storage of all the technical data necessary for supporting the engine maintenance. Examples of technical data include:

a. Operations and maintenance instructions;
b. Neutral/ digital format;
c. Task packages; and
d. Fixed frame/ navigation.

The workstation would also be responsible for mainframe interfaces as required. This interface would support the exchange of information between the maintenance technician and the overhaul facility. Schedule data, often important in making maintenance decisions, could be retrieved via the mainframe interface.

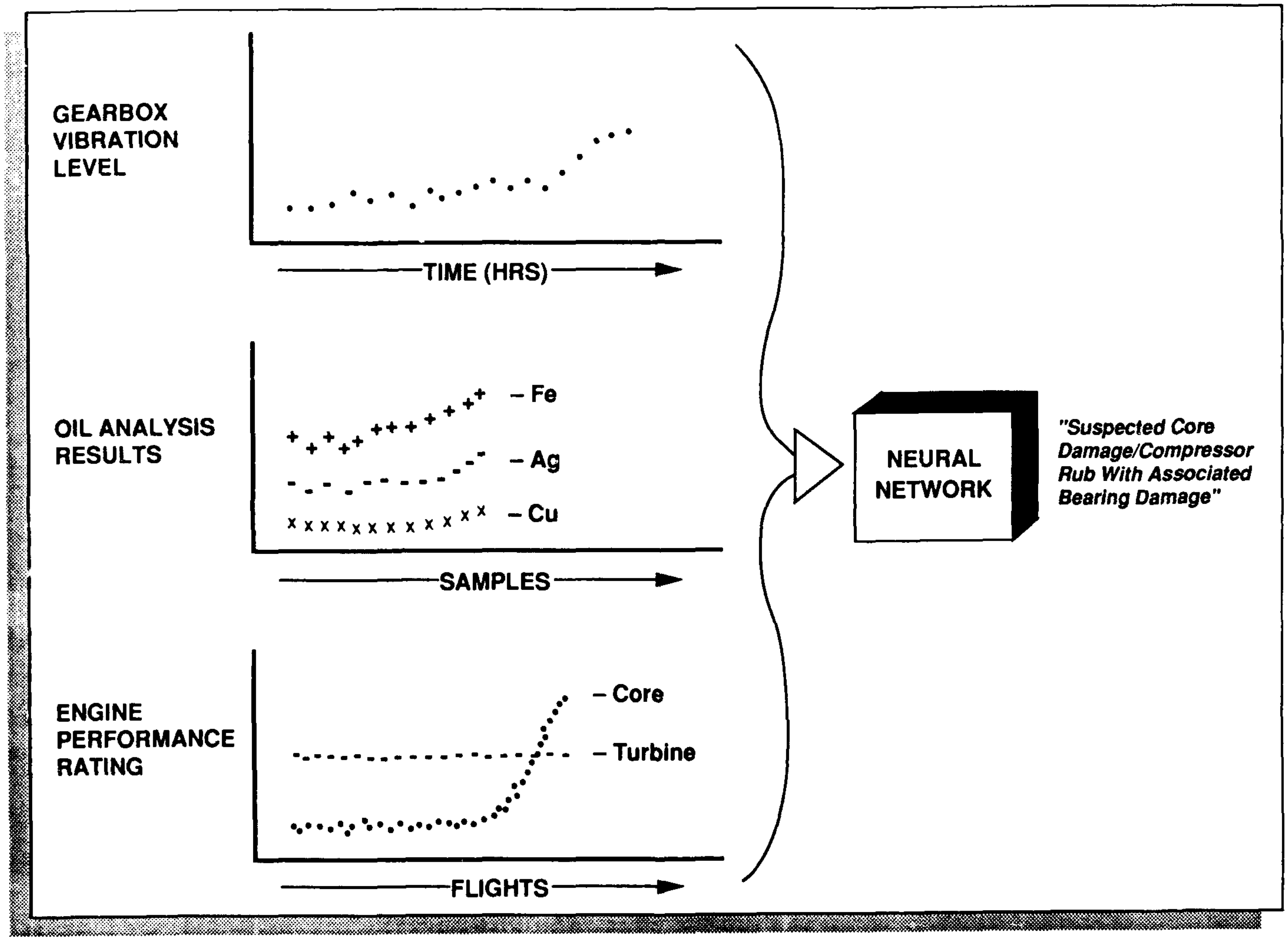


FIGURE 5-9 Pattern Recognition With Neural Networks

5.5.2 Portable Diagnostic Tool

The portable diagnostic tool would be comprised of a laptop computer and an RF modem linked together via a communications link such as an RS232. SCT, over the course of other system developments, has investigated several options for radio communications devices. The suggested package is the result of considerable investigations.

The functions of the portable diagnostic tool can be divided into two distinct groups; information capture and technical data delivery. Information capture includes the following items:

a. Inspection data. The technician enters the results of engine inspections directly into the portable diagnostic tool;

b. Operating data. The aircraft is down loaded after flight by the maintenance technician directly into the portable diagnostic tool;

c. Pilot reports. Pilot discrepancy reports, as well as manually recorded parameter values can be obtained by the maintenance technician and entered into the system via the portable diagnostic tool; and

d. Task accomplishment. The maintenance technician can report the successful completion of a maintenance task (including the result of maintenance actions and inspections) into the historical database via the portable diagnostic tool.

Technical data delivery includes the following items:

a. Troubleshooting. An expert system troubleshooting aid would step the maintenance technician through the diagnostics procedure based upon established technical data procedures for the chosen discrepancy;

b. Operating instructions. The portable diagnostic tool would deliver to the technician the relevant operating instructions, including figures, necessary for the particular maintenance action; and

c. Maintenance task. The system would inform the maintenance technician of the task to be performed and

would provide information on the order in which tasks should be performed.

5.6 SUMMARY

The system concept satisfies the requirements of the first line maintenance technician by providing an evaluation of the overall health of the engine and the status of critical rotating components with regards to their probability of failure. The expert system will recommend additional tests or maintenance procedures as indications of rotating parts failure are discovered. Recommendations could include additional non-destructive inspections, operational checks, maintenance procedures or restricted operational use of the engine.

The requirements of the engine overhaul mechanic/engineer would be satisfied in the form of providing detailed parametric data and expert system recommendations for overhaul actions. The following is a list of actions that are under consideration:

a. Cryogenic conditioning of turbine wheels to increase life;
b. Replacement of specific components; and
c. Recommendations for including pre-identified modifications.

The additional data available to the overhaul engineer would support engineering changes and recommendations for retrofit improvements for engines throughout the operational fleet.

6. CONCLUSIONS

The Phase I research has contributed to the design of an integrated system for predicting failure in turbine engines. The system concept is the final product of this Phase I effort. The design features a desktop workstation and hand held units (a laptop computer and a Radio Frequency Modem linked together via a RS232 communications link) to provide maintenance personnel with complete information necessary for detecting and diagnosing engine failures. The Phase I report has identified the potential data sources for the TED system and has provided a summary of the trade-offs involved in employing each of these potential data sources. A natural continuation is to build the prototype to prove the concept and test the assumptions upon which the system is based.

APPENDIX A

TURBINE ENGINE DIAGNOSTICS DOCUMENTS INDEX

TITLE AIMS for Helicopters

INDEX NO. 01OAD.01SCT-TED

AUTHOR D. Jesse; Bristow Helicopters Limited
D.W. Barr; Plessey Avionics
PUBLISHER DLR, Institut fur Flugfuhrung - Proceedings of 15th AIMS Symposium
DATE September, 1989
DOC TYPE Symposium Paper

ABSTRACT
Helicopters differ from fixed wing aircraft in that most of the flight safety critical components cannot be duplicated. In order to improve flight safety and to reduce operating costs, an AIMS system specifically designed for helicopters is needed. This joint paper between Bristow Helicopters Ltd. and Plessey Avionics considers the current progress on HUM systems, and the need to satisfy the new CAA legislation on Flight Data Recorders for Helicopters which becomes mandatory in February 1991. The result is a joint development programme which integrates both functions and provides proven hardware in time for the legislation, and of practical use to the operators.

TITLE Allison Gas Turbine: in the Forefront of Vertical Flight Propulsion R&D

INDEX NO. 02OAD.02SCT-TED

AUTHOR L. Scipioni, Jr.; Allison Gas Turbine Division, General Motors

PUBLISHER Vertiflite
DATE May/June 1988
DOC TYPE Magazine Article

ABSTRACT
Allison Gas Turbine Division of General Motors is the major producer of light helicopter turboshaft engines. In the 1980s, several turbine engine development programs were started to address 1990s' requirements. The T800, a 1200-SHP engine, is a new, small engine for the Army's Light Helicopter Experimental Program (LHX). The V-22 Osprey Tilt Rotor uses the Allison T406 engine, a large turbine engine in the 6000-SHP category. The future thrust is towards lower cost, smaller, more reliable and powerful turbines. Research and development areas include: investigation of unique cycles, doubled power to weight ratio, greater than 25% reduction in SFC, increased reliability/maintainability, better affordability, improved operational capability, etc. The technologies needed to support these development areas include improved high temperature materials, smaller components and maintainability design characteristics.

TITLE An Analysis of Air Force Management of Turbine Engine Monitoring Systems (TEMS)

INDEX NO. 03OAD.03SCT-TED

AUTHOR Capt. E.B. Hubbard III, Capt. G.A. Swecker; Air Force Institute of Technology, Wright Patterson AFB
PUBLISHER Air Force Institute of Technology, Wright Patterson AFB
DATE June 1980
DOC TYPE Master's Thesis Report

ABSTRACT
Turbine Engine Monitoring Systems (TEMS) are engine health monitoring and diagnostics tools being developed and tested for use on Air Force engines in order to improve and reduce the cost of engine maintenance and management and to aid in the implementation of On Condition Maintenance. Previous researchers have described the major features of TEMS, analyzed the results of development and test efforts, and identified problems which must be overcome. This study examines the problem of fragmentation which exists in the Air Force management of TEMS development and testing. The authors describe and analyze the overall Air Force management of TEMS. Management problems were identified and classified into three major areas: structure and role problems, information flow and integration problems, and leadership and command problems. Four alternative management concepts were analyzed. Based on this analysis, the authors recommend that the management structure be modified, and a TEMS Task Force be established to more effectively utilize TEMS for Air Force engine maintenance and management.

TITLE An Automated Between Flight Visual Inspection Condition Monitoring System

INDEX NO. 04OAD.04SCT-TED

AUTHOR P.T. Coleman, E. Nemeth, J.M. Maram, A.M. Norman; Rockwell International, Rocketdyne Division
PUBLISHER AIAA - AIAA/ASME/SAE/ASEE 25th Joint Propulsion Conference
DATE July, 1989
DOC TYPE Conference Paper

ABSTRACT
This paper discusses the automation of between flight visual inspections for reusable rocket engine system maintenance. A review of current turnaround maintenance procedures and the application of automated inpsection methods is discussed. In addition, the application of vision processing to images acquired by current methods of visual inspection is examined.

TITLE Design of Digital Self-Selecting Multivariable Controllers for Jet Engines

INDEX NO. 05OAD.05SCT-TED

AUTHOR A.H. Jones, B. Porter, A. Chrysanthou; Centre for Instrumentation and Automation, University of Salford

PUBLISHER AIAA - AIAA/SAE/ASME/ASEE 26th Joint Propulsion Conference

DATE July, 1990

DOC TYPE Conference Paper

ABSTRACT

In this paper, the tunable digital set-point tracking PI controllers for linear multivariable plants developed at Salford are extended to deal with plants with more output variables than input variables. This extension is effected by delineating the concept of asymptotic positive- real closed-loop transfer function and by using this concept in the design of self-selecting highest- or lowest-wins controllers. The effectiveness of the resulting design methodology is illustrated by designing a self-selecting lowest-wins set-point tracking PI controller for a two-input five-output turbofan jet engine.

TITLE Diagnostics in the Extendable Integrated Support Environment

INDEX NO. 06OAD.06SCT-TED

AUTHOR J.R. Brink, Ph.D.; Battelle Columbus Division
P. Storey; Sacramento Air Logistics Center, MMESD

PUBLISHER NASA Lyndon B. Johnson Space Center - SOAR '88 Workshop

DATE November, 1988

DOC TYPE Conference Paper

ABSTRACT

EISE is an Air Force developed real-time computer network consisting of commercially available hardware and software components to support systems level integration, modifications and enhancements to weapons systems. The EISE approach offers substantial potential savings by eliminating unique support environments in favor of sharing common modules for the support of operational weapon systems.

An expert system is being developed that will help support diagnosing faults in this network. This is a multi-level, multi-expert diagnostic system which uses experiential knowledge relating symptoms to faults and also reasons from structural and functional models of the underlying physical model when experiential reasoning is inadequate. The individual expert systems are orchestrated by a supervisory reasoning controller, a meta-level reasoner which plans the sequence of reasoning steps to solve the given specific problem. The overall system, termed the Diagnostic Executive, accesses systems level performance checks and error reports, and issues remote test procedures to formulate and confirm fault hypotheses.

TITLE Digital Data System Expected to Benefit Defense and Industry

INDEX NO. 07OAD.07SCT-TED

AUTHOR B.D. Nordwall

PUBLISHER Aviation Week & Space Technology
DATE February, 1990
DOC TYPE Magazine Article

ABSTRACT
The Computer-aided Acquisition and Logistic Support (CALS) program is a Pentagon program to shift technical weapon systems data from paper to digital storage. The first phase of the program ran from 1985 to 1989, and emphasized coordination with industry, infrastructure plans and initial standards. The second phase is scheduled from 1990 to 1995, during which a CALS test network will be established. The third phase, from 1995 to 2000, will have CALS shifting to wide-scale industrial networks. The services have designated lead weapon systems to use CALS: the LHX helicopter and the Abrams M1 tank from the Army, the A-12 advanced tactical aircraft, the V-22 Osprey, and the SSN-21 Seawolf submarine from the Navy and the Advanced Tactical Fighter from the Air Force.

The success of CALS depends on creation of standards and technology. Creating a standard defense/industry interface poses an immediate problem. Another issue is how far to retrofit CALS since 50-80% of existing weapon systems will still be around in 2000.

TITLE Engine Monitoring

INDEX NO. 08OAD.08SCT-TED

AUTHOR S. Royek, R. Casagrande, P. Emile, D. Garcia, G. Gozemba; Ametek Aerospace Products

PUBLISHER Avionics
DATE January, 1990
DOC TYPE Magazine Article

ABSTRACT
The most sophisticated Engine Monitoring Systems (EMS) are on several military aircraft. Engine data is collected and analyzed, alerting the pilot to abnormal conditions. Also, vibration analysis combined with speed, temperature, pressure, engine cycles, life usage, and time/date stamping create maintenance schedules for each engine. In a U.S. Navy study of an earlier EMS system, maintenance per flight hour and premature engine removals were reduced and actual flight hours were increased.

TITLE Evaluation of a Fault Tolerant Digital Engine Controller

INDEX NO. 09OAD.09SCT-TED

AUTHOR W.E. Wright, J.C. Hall; Advanced Technology Control Systems, GE
Dr. J.J. Deyst, Dr. R.E. Harper; Charles Stark Draper Laboratory

PUBLISHER AIAA - AIAA/ASME/SAE/ASEE 25th Joint Propulsion Conference

DATE July, 1989

DOC TYPE Conference Paper

ABSTRACT

In order to address aircraft engine control reliability and redundancy issues associated with advanced aircraft, the Air Force initiated two programs known as INTERFACE I and II - L. The acronym INTERFACE is derived from INTEgrated Reliable FAult-tolerant Control for Engines. The Advanced Technology Controls organization of General Electric Aircraft Engines participated as a prime contractor in both INTERFACE programs. INTERFACE I incorporated a military standard 1750A 16-bit processor architecture programmed in Jovial and INTERFACE II - L utilizes military standard 1815 Ada in combination with a 32-bit processor. Both programs produced triple redundant engine controls and feature a tightly synchronized, Byzantine Resilient fault-tolerant computer architecture developed by the Charles Stark Draper Laboratory. This paper presents an evaluation of the INTERFACE I engine control as well as preliminary evaluation of the INTERFACE II control. The results of investigations into fault-tolerant parallel processing for engine controls will also be presented.

TITLE Full Authority Digital Electronic Engine Control System Provides Needed Reliability

INDEX NO. 10OAD.10SCT-TED

AUTHOR D.A. Fiebig; Controls Engineering, Government Engine Business, Pratt and Whitney

PUBLISHER AIAA - AIAA/SAE/ASME/ASEE 26th Joint Propulsion Conference

DATE July, 1990

DOC TYPE Conference Paper

ABSTRACT

During the past decade the reliability of control systems for Pratt & Whitney military engines has improved by a factor of six. An operational engine, of current configuration, now requires the removal of a control system component for maintenance action less than once a year. This significant improvement is the result of a concentrated effort to address the elements of product quality and reliability at all stages of development including design, development, manufacture, and deployment. In addition to basic design improvements which rely on digital electronic control modes, specific design, development test and production quality improvement initiatives have contributed to the overall reliability enhancement. Such programs as environmental stress screening (ESS), combined environment reliability testing (CERT), durability testing, production readiness programs, field service evaluations, and manufacturing process reviews made significant improvements in product reliability. Throughout the next decade significant improvements in reliability will continue to be made because of the incorporation of further digital electronic control enhancements (dual channel full authority digital electronic control systems) and the application of Propulsion and Power System Integrity Program (PPSIP), concurrent engineering and Total Quality Management (TQM) initiatives for the design, development and production programs.

TITLE Integrated Avionics

INDEX NO. 11OAD.11SCT-TED

AUTHOR R.E. Friday; King Radio Division, Allied Signal Corporation
M.A. Card; Bendix Avionics Division, Allied Signal Corporation

PUBLISHER Aerospace Engineering

DATE April, 1988

DOC TYPE Magazine Article

ABSTRACT

The trend in avionics systems for general aviation is towards the integration of sophisticated navigation, display and flight control systems. One major hinderance to full integration has been the ranging degree of incompatibility between components that typically comprise an avionics system. Recently introduced general systems include electronic flight instrument systems (EFIS), long-range navigation (LRN) systems and digital flight control systems (FCS). New display systems, data transfer methods, and cockpit management tools are being developed to deal with the increased amount of data available to the flight crew. Among the technologies being investigated are flat panel displays, fly-by-wire control systems, voice command and control, high-speed bi-directional data buses and fault tolerant data management computers.

TITLE Power Analyzer and Recorder (PAR)

INDEX NO. 12OAD.12SCT-TED

AUTHOR Teledyne Avionics

PUBLISHER Teledyne Avionics

DATE

DOC TYPE Product Brochure

ABSTRACT

PAR is Teledyne Avionics' Power Analyzer and Recorder. It is a turbine engine health monitor designed to analyze and record aircraft operation and display information to the pilot. PAR continuously monitors N1, N2, Np/Nr, EGT, and Torque, and generates all Atmospherics - PALT, DALT, OAT. Data can be downloaded to a printer or PC via a RS232 communications port.

TITLE Reconfigurable Integrated System Architecture for Future Monitoring Systems

INDEX NO. 13OAD.13SCT-TED

AUTHOR W.A. Clearwaters; Helitune Ltd.

PUBLISHER DLR, Institut fur Flugfuhrung - Proceedings of 15th AIMS Symposium
DATE September, 1989
DOC TYPE Symposium Paper

ABSTRACT
Next generation monitoring systems will require capabilities not found in current systems. In order to meet the challenges posed by these systems, Helitune has instituted the ARIA (Advanced Reconfigurable Integrated Architecture) program to capitalize on recent advances in computer technology particularly in the areas of Object Oriented Programming Systems, VLSI, and database and CASE systems. ARIA proposes to employ the power inherent in the object paradigm to address the problems of integration and reconfiguration in future monitoring systems. ARIA also encompasses a hardware element to develop a modular, distributed hardware set and a software toolbox for the reliable implementation and maintenance of these new systems.

TITLE A Self Diagnostic System for Piezoelectric Sensors

INDEX NO. 14OAD.14SCT-TED

AUTHOR W.J. Atherton, Ph.D., P.M. Flanagan, Ph.D.; Cleveland State University

PUBLISHER AIAA - AIAA/ASME/SAE/ASEE 25th Joint Propulsion Conference
DATE July, 1989
DOC TYPE Conference Paper

ABSTRACT
A technique for determining the mounting conditions of a piezoelectric accelerometer is presented. This technique electrically stimulates the piezoelectric element in the "diagnostic" frequency band measuring the electrical frequency response characteristics across a capacitive load impedance. The diagnostic frequency band is typically much higher than the operating bandwidth of the accelerometer. The resonant frequencies of the accelerometer are included in the diagnostic band. By monitoring the shift in these resonant frequencies, via electrical stimulation techniques, certain diagnostic conditions including mounting conditions can be determined. Experimental data from a compression mode accelerometer is used to demonstrate this technique.

TITLE Systems Approach to Engine Monitoring

INDEX NO. 15OAD.15SCT-TED

AUTHOR G. Harris; Data Trend

PUBLISHER Avionics
DATE February, 1986
DOC TYPE Magazine Article

ABSTRACT
The JET (Jet Electronics and Technology) ETM600 is an inflight engine monitoring system that provides operating parameter trend analysis graphs by means of a removable module that stores the data. The result is substantially improved maintainability and instrument calibration.

TITLE Trend Analysis and Diagnostic Codes for Training Purposes

INDEX NO. 16OAD.16SCT-TED

AUTHOR G. Torella; Italian Air Force Academy

PUBLISHER AIAA - AIAA/SAE/ASME/ASEE 26th Joint Propulsion Conference
DATE July, 1990
DOC TYPE Conference Paper

ABSTRACT
The importance and the necessity of the simulation during the training of the personnel as well as during the "On Condition" maintenance activities are discussed. Numerical codes have been developed for this aim and the results for trend analysis and for diagnostic calculations are presented. The paper deals with different fault situations and with engines with different configuration.

TITLE AIMS for Helicopters

INDEX NO. 01HED.17SCT-TED

AUTHOR D. Jesse; Bristow Helicopters Limited
D.W. Barr; Plessey Avionics

PUBLISHER DLR, Institut fur Flugfuhrung - Proceedings of 15th AIMS Symposium

DATE September, 1989

DOC TYPE Symposium Paper

ABSTRACT

Helicopters differ from fixed wing aircraft in that most of the flight safety critical components cannot be duplicated. In order to improve flight safety and to reduce operating costs, an AIMS system specifically designed for helicopters is needed. This joint paper between Bristow Helicopters Ltd. and Plessey Avionics considers the current progress on HUM systems, and the need to satisfy the new CAA legislation on Flight Data Recorders for Helicopters which becomes mandatory in February 1991. The result is a joint development programme which integrates both functions and provides proven hardware in time for the legislation, and is of practical use to the operators.

TITLE Airborne Integrated Monitoring System

INDEX NO. 02HED.18SCT-TED

AUTHOR A.H. Neubauer, Jr.; Teledyne Controls

PUBLISHER

DATE

DOC TYPE Conference Paper

ABSTRACT

This paper addresses the goals and issues associated with on-board monitoring techniques and suggests approaches for dealing with them. Both input and output signal interface goals will be discussed along with the microprocessor and memory devices necessary to implement a viable monitoring system.

The major goal for input and output interfaces is to achieve a workable system that operates completely in the digital domain. Although this is not always practical, the achievement of such a goal will reduce system complexity and aircraft wiring. For memory and recording the goal is to implement cost effective, solid-state, nonvolatile devices that can provide for error free and long lasting storage of data while withstanding the hostile environment. The goal for computer technology is to make maximum use of existing devices but to retain the flexibility necessary to accept new, high capacity devices as they come on the market.

The central integrated checkout system being implemented on the V-22 Osprey tiltrotor aircraft will be used as the example of current technology.

TITLE Another Day with an EMS Mechanic

INDEX NO. 03HED.19SCT-TED

AUTHOR D.L. Bonney; St. Louis Helicopter Airways

PUBLISHER Journal of Air Medical Transport
DATE December, 1989
DOC TYPE Journal Article

ABSTRACT

This article chronicles a typical workday for an Emergency Medical Service (EMS) mechanic. He performs one zone of the Approved Aircraft Inspection Program (AAIP) on a BO-105 Messerschmitt-Bolkow Blohn helicopter.

TITLE Application of Constraint Suspension Techniques to Diagnosis in Helicopter Caution/Warning Systems

INDEX NO. 04HED.20SCT-TED

AUTHOR G. Glenn; McDonnell Douglas Helicopter Company

PUBLISHER American Helicopter Society - National Specialists Meeting
DATE April, 1988
DOC TYPE Conference Paper

ABSTRACT

This paper describes research done at McDonnell Douglas Helicopter Company in applying artificial intelligence techniques to the task of advising a helicopter crew of events taking place in their aircraft subsystems.

As part of the U.S. Army Apache Enhanced Diagnostic System Contract (EDS), a demonstrator system was developed that is capable of simulating multiplex bus traffic of caution/warning related data, and invoking a diagnostic module upon detection of an abnormal condition. Problem indicators are prioritized based on severity and displayed on a simulated up-front cockpit display and multifunction display. The demonstrator attempts to provide a diagnosis, where possible, and also provides advice about actions to be performed in response to critical situations. Severe problems are announced using an aural annunciator with digitally sampled stored messages. The diagnostic module utilizes a technique called candidate generation via constraint suspension to prune the list of suspected components while diagnosing a failure. Constraint suspension is a form of model-based reasoning that allows faults to be diagnosed by modeling the intended correct behavior of the system and comparing the outputs of the model with the true behavior of the system. This technique, which was first investigated by Randall Davis at the Massachusetts Institute of Technology under DARPA funding, shows potential for use as a diagnostic tool in ground-based as well as airborne systems.

TITLE Automatic Engine Monitoring Field Installation and Reliability Evaluation Report

INDEX NO. 05HED.21SCT-TED
AUTHOR B.M. Battles; Bell Helicopter Textron

PUBLISHER Helicopter Assocation International
DATE July, 1989
DOC TYPE Project Report
ABSTRACT
This report concludes an evaluation of automatic engine monitoring equipment, which began in November 1985. The final phase of the project was a field installation and reliability evaluation, during which equipment was installed in operational aircraft. Semco Instruments was the only monitor manufacturer that met all the HAI requirements. Six attachments to the report summary give information on the operators and their aircraft, the field installations, the performance of each system, the systems' functions and parameters, the operators' comments, and other ancillary operator's comments beyond the scope of the evaluation.

TITLE Bell's Design Approach for Future Rotorcraft Maintenance/Diagnostics

INDEX NO. 06HED.22SCT-TED
AUTHOR H. Franks, R. Samson, R. Patten, J. Emery; Bell Helicopter Textron

PUBLISHER American Helicopter Society - 46th Annual Forum
DATE May 1990,
DOC TYPE Conference Paper
ABSTRACT
This paper describes an overview of programs under way at Bell in which advanced maintenance/diagnostics technology guidelines are being developed and applied in the engineering design process. Examples of company-sponsored work and contracted programs are described, addressing the requirements for near-term guidelines and those leading into the next century. An overview of a future specification being developed by the Air Force called Generic Integrated Maintenance and Diagnostics (GIMADS) is discussed, with emphasis given to (on) the mechanical systems diagnostics portion of the specification development. Plans for incorporating "lessons learned" into Bell's computer-aided engineering (CAE) activities are discussed.

Examples of programs addressing onboard maintenance/diagnostics aids are summarized, including health, usage/lifing, monitoring systems (HUMS) for commercial helicopters, and the health monitoring system to be used on the V-22 Osprey. An overview of a study contract called Advanced Architecture Maintenance/Diagnostic Assessment (AAM/DA) is discussed. This program, funded by the U.S. Army Aviation Applied Technology Laboratory (AATD), is studying advanced maintenance/diagnostics requirements and the development of guidelines for incorporating maintenance/diagnostics into advanced avionics architecture.

TITLE CHC's High-Stakes Venture into Helicopter Maintenance

INDEX NO. 07HED.23SCT-TED
AUTHOR H. McLean

PUBLISHER Rotor & Wing International
DATE April, 1990
DOC TYPE Magazine Article
ABSTRACT
Canadian Helicopters Corporation's (CHC) maintenance arm is the Engineering Support Division. The division began as Okanagan Helicopters, the largest of the companies now part of CHC, and after a downturn in the early 1980s, the division now services customers throughout Canada and in over a dozen countries. The division's services include maintenance on the Sikorsky S-61, engine overhauls on Allison 250 series, GE CT58, Pratt & Whitney PT6, Turbomeca Arriel and others, parts for all major helicopter models, overhaul on Bell and Aerospatiale components and accessories, avionics and instrument services, precision machine shop work, nondestructive testing and major airframe overhauls and rebuilds. International business accounts for about 45% of the division's revenues. The division is targeting the Canadian Department of National Defense (DND) for future business.

TITLE A Comprehensive Diagnostic System for the T800-APW-800 Engine

INDEX NO. 08HED.24SCT-TED
AUTHOR A. Bilodeau, K.S. Collinge; Textron Lycoming

PUBLISHER
DATE
DOC TYPE Conference Paper
ABSTRACT
In responding to U.S. Army requirements to improve LHX weapon system maintenance to the greatest extent possible, Textron Lycoming created an advanced engine mounted system for the T800-APW-800 gas turbine engine. Although named the Engine Monitoring System (EMS), it is much more than the name implies. It is a comprehensive diagnostic system which monitors, diagnoses and provides maintenance and repair instructions and mission data records.

This EMS leads diagnostic technology with its ability to continuously acquire, validate, monitor, analyze, record and manage all engine parameters. The EMS provides both flight and maintenance crew support with information on engine performance, condition, operational history, maintenance requirements, repair instructions and logistic information. With this information, automated diagnosis, maintenance and repair can be accomplished in a timely manner. All of this information is available to flight and maintenance crews and to fleet data collection centers.

The system minimizes false diagnosis, reducing NEOF (No Evidence Of Failure) returns to depot. This is accomplished through the combination of automatic and semi-automatic diagnosis. The EMS maximizes engine availability, maintainability, reliability and operability while it minimizes engine life cycle costs.

TITLE Development of a Prototype H-46 Helicopter Diagnostic Expert System

INDEX NO. 09HED.25SCT-TED

AUTHOR T.G. Gadzala; Naval Postgraduate School

PUBLISHER Naval Postgraduate School
DATE September, 1987
DOC TYPE Master's Thesis Report

ABSTRACT

This study was undertaken to demonstrate the feasibility of applying expert system technology to the Navy's H-46 helicopter maintenance process. A microcomputer-based prototype known as a computer-aided diagnostic system (CADS) was developed for this purpose. Given a helicopter electrical or hydraulic system discrepancy, the troubleshooter interacts with CADS to find the cause. The prototype CADS was developed utilizing the M.1 knowledge-based system development tool by Teknowledge, Inc.

The complexity of helicopter systems diagnosis, and inadequacies of the maintenance manuals, often result in unnecessary removal of system components. The prototype CADS is intended to demonstrate that a fully developed system, containing all the formal and heuristic knowledge of H-46 diagnostic information, could eliminate these problems. Also, such a diagnostic system could provide a comprehensive, stable diagnostic knowledge base, regardless of personnel turnover.

This study includes a description of current helicopter maintenance procedures, and how the integration of CADS could improve this process. Also included are descriptions of expert systems and the M.1 knowledge-based system development tool: how they work, and their applicability to structured selection problem-solving. The development and testing strategies used for CADS are discussed in detail. Results, conclusions, and recommendations for further study are provided.

TITLE Development of a Structural Integrity Recording System (SIRS) for U.S. Army AH-1S Helicopters

INDEX NO. 10HED.26SCT-TED

AUTHOR J.G. Dotson, A.W. Kolb; Technology Incorporated

PUBLISHER Applied Technology Laboratory, AVRADCOM
DATE May, 1982
DOC TYPE Final Report

ABSTRACT

A follow-on research and development program to implement a Structural Integrity Recording System (SIRS) for the Army AH-1S helicopter was conducted by developing a computer program to reduce recorded aircraft usage data. The program, entitled Fatigue Damage Assessment System (FDAS), was designed to run on the AVRADCOM computer. An improved lift-link-mounted strain sensor was also developed. The sensor was laboratory-tested and deemed ready for follow-on application testing in regard to monitoring helicopter gross weight, and take-off and landing detection.

TITLE Diagnostic and Condition Monitoring System Assessment for Army Helicopter Modular Turboshaft Engines

INDEX NO. 11HED.27SCT-TED

AUTHOR H.J. John; General Electric Company, Aircraft Engine Group

PUBLISHER Applied Technology Laboratory, AVRADCOM
DATE October, 1980
DOC TYPE Final Report

ABSTRACT

Needs for and means of improving D&CM and troubleshooting to modules and LRUs for the T700-GE-700 engine in Army environment were studied. Recommendations are: (1) Do not modify existing METS for modular fault isolation. However, do computerize the acquisition of the overall engine performance data, (2) introduce the slave chip detector to the depot, (3) expand evaluation of the control system analyzer by Black Hawk companies, (4) support the development of degaussing chip detector, (5) initiate Phase I of multipurpose airborne D&CM system which combines performance, life, overtemp and chip detector monitors, and (6) continue to acquire T700 field data and develop a method to quantify D&CM payoffs such as better engine availability.

TITLE EH-101 Cockpit Displays: Keeping It Plain and Simple

INDEX NO. 12HED.28SCT-TED

AUTHOR S. Coyle

PUBLISHER Rotor & Wing International
DATE May, 1990
DOC TYPE Magazine Article

ABSTRACT

The electronic displays and software used in the European Helicopters Industries (EHI) EH-101 multipurpose helicopter confer several major advantages: different end uses (military versus civil) have different display output; different flight modes (start-up versus cruise) also change mode; and different applications (low altitude versus high altitude) can have different displays. The display and/or avionics can differ by installation (e.g. MIL-STD-1553B wiring versus ARINC429 civil wiring), by switch selection, and be automatically based on sensor data. The advantages are many, including uncluttered display for swift pilot reaction to emergencies, versatility for different helicopter configurations (military versus civil), and better maintenance records.

TITLE Emerging New Technologies at Sikorsky Aircraft

INDEX NO. 13HED.29SCT-TED

AUTHOR Dr. R.K. Shenoy; Research and Development Planning, Sikorsky Aircraft Division, United Technologies Corp.

PUBLISHER Vertiflite

DATE March/April, 1990

DOC TYPE Magazine Article

ABSTRACT

Currently Sikorsky Aircraft is adapting advances in electronics technology to make rotorcraft more reliable and competitive. Expert Systems & Artificial Intelligence, Advanced Simulation, and Engineering Automation top the list of such emerging technologies and are briefly described in this article. In addition to these areas, to counter the improvements in detection technology, Low Observables (L.O.) are emerging as another technology of interest. Considerable investment and progress has been made at Sikorsky Aircraft in L.O. technologies, which include radar signature control and infra-red signature control. Due to the nature of this subject, only a few details of the radar signature control technology will be discussed.

TITLE An Experimenter Operator Station for Helicopter Flight Simulator Research and Training

INDEX NO. 14HED.30SCT-TED

AUTHOR T.A. Kaye; Bell Helicopter Textron
L.M. Freeman; Aerospace Engineering, University of Alabama

PUBLISHER AIAA

DATE 1989

DOC TYPE Conference Paper

ABSTRACT

The increasing use of flight simulators for pilot training is primarily driven by economic and safety considerations. A very labor intensive research effort is usually required in order to verify the basic assumption that the skills a pilot develops in the simulator are the same as the skills required to fly the actual aircraft. Studies that demonstrate a positive transfer of learning to the pilot typically require human factors researchers to perform many repetitious and tedious tasks, particularly in the area of data acquisition and statistical analysis.

TITLE Expert Systems for Helicopter Pilots

INDEX NO. 15HED.31SCT-TED

AUTHOR W. Shaneyfelt; Defense Avionics Systems Division, Honeywell

PUBLISHER Avionics
DATE January, 1990
DOC TYPE Magazine Article

ABSTRACT

The Helicopter Pilot's Emerging Situation Advisor (H/PESA) is a prototype demonstration of a cockpit expert emergency advisory system. The system displays, analyzes and evaluates information, and recommends actions. In addition to factual information, the knowledge base includes rules of inference. The organization of the knowledge base was determined, in part, by execution speed. During an in-flight emergency a pilot cannot wait for an expert system to go through a lengthy analysis. Speed gains have been achieved by organizing rules in the knowledge base into a hierarchy.

TITLE Fixed-Gain Versus Adaptive Higher Harmonic Control Simulation

INDEX NO. 16HED.32SCT-TED

AUTHOR LTC K.P. Nygren; Dept. of Civil & Mechanical Eng., U.S. Military Academy
D.P. Schrage; CERWAT/School of Aerospace Eng., Georgia Inst. of Tech.

PUBLISHER American Helicopter Society
DATE July, 1989
DOC TYPE Journal Paper

ABSTRACT

A computer simulation of helicopter vibration reduction using higher harmonic control (HHC) is developed by incorporation of an HHC solution procedure in the Dynamic System Coupler (DYSCO) Program. The simulation can model almost any HHC control and identification scheme tested to date, including stochastic control. The adequacy of fixed-gain as opposed to adaptive control has recently been in question. Both of these HHC methods are simulated in steady and constant-thrust maneuvering flight, as well as conditions of incorrect transfer matrix initialization. The results indicate fixed-gain control can adequately reduce vibrations for the helicopter modeled, as long as the flight condition is within about 20 knots of the flight conditions used to calculate gains.

TITLE A Full Authority Digital Electronic Control System for Multi-Engine Rotorcraft

INDEX NO. 17HED.33SCT-TED

AUTHOR D. Petro; AVCO Lycoming Division / A.J. Gentile; Chandler Evans Inc.
A.B. Foulds; Hawker Siddeley Dynamics Engineering

PUBLISHER The City University - 11th European Rotorcraft Forum
DATE September, 1985
DOC TYPE Conference Paper

ABSTRACT

Conventional engine control systems for turbine-powered rotorcraft have become increasingly complex in the process of striving for optimized performance of the power plant and aircraft. Traditionally, the only method of achieving this goal was to increase the level of functional sophistication within the control through nonelectronic techniques.

Using a proposed RAF application as an example, this paper reviews the basic requirements and need for incorporation of a full authority digital electronic control system on an existing twin-engine military helicopter. The unique selection process and component configuration are discussed, which involved international collaboration among several organizations utilizing the latest concepts in electronic technology. The technical details and functional performance of the digital electronic control system are described relative to fulfilling the particular requirements of a tandem rotor helicopter. Finally, operational and installation features of the engine control system, such as reliability, maintainability, diagnostics, history recording, health monitoring, aircraft incorporation and cost-of-ownership are summarized to ensure that the original design philosophy and goals of the program would be satisfied.

TITLE The Future Roles of Flight Monitors in Structural Usage Verification

INDEX NO. 18HED.34SCT-TED

AUTHOR A.E. Thompson; Sikorsky Aircraft Division, United Technologies Corp.

PUBLISHER American Helicopter Society - National Technical Specialists Meeting
DATE October, 1988
DOC TYPE Conference Paper

ABSTRACT

Structural substantiation of helicopter dynamic components for fatigue has traditionally combined three elements - component strength, aircraft flight loads, and an assumed usage spectrum. While component strength and flight loads are measured, most substantiating usage spectra are based on general military or civil specifications, contractor experience, or user and pilot surveys. All of these methods are filled with assumptions, and cannot begin to address the mission profile variabilities. Since helicopter dynamic component replacement times can be very sensitive to the assumed usage spectrum, it is necessary to define a "realistic mission profile". Past efforts in this direction have included detailed load/criteria studies, mission simulation flight tests, and pilot/user questionnaires. The development of flight monitors will provide major opportunities to understand aircraft usage. This paper discusses past and current limited aircraft monitoring programs at Sikorsky. It then describes future monitors under development which will provide fleet-wide continuous usage monitoring, and regime recognition algorithms which will provide rate of occurrence data for all critical flight conditions. It is emphasized that monitor data must be used cautiously. The engineer must use quality data, based on statistically significant survey programs. But most important, the traditional conservatism of the substantiation process must not be stripped away haphazardly. The reliability of a substantiation depends upon a balance of realism in the usage spectrum and conservatism in the overall substantiation process.

TITLE Health Monitoring of Helicopter Gearboxes

INDEX NO. 19HED.35SCT-TED

AUTHOR D.G. Astridge; Westland Helicopters Ltd.

PUBLISHER Aeronautic & Astronautic Assoc. of France - 8th Europ. Rotorcraft Forum
DATE August/September, 1982
DOC TYPE Conference Paper

ABSTRACT

The various problems posed for gearbox health monitoring are discussed, and the solutions applied to the Westland 30 helicopter are described. These embrace the transition from traditional, well known laboratory based techniques and subjective evaluations, to the on-line facilities of future aircraft such as the EH101, and growth versions of Westland 30.

TITLE The Health and Usage Monitoring of Helicopter Systems - The Next Generation

INDEX NO. 20HED.36SCT-TED

AUTHOR J.D. Roe, D.G. Astridge; Westland Helicopters Ltd.

PUBLISHER Reprinted by AIAA
DATE
DOC TYPE Conference Paper

ABSTRACT

The paper discusses the relevance of health and usage monitoring systems to the improvement of airworthiness and life cycle costs of helicopters, addressing the findings and recommendations of the HARP report/review of helicopter airworthiness (CAP 491, CAA, June 1984). The advanced on-board maintenance processor systems currently being designed for the Westland 30 Series 300 and EH101 helicopters are described, covering sensors, interfaces, data links, processors and output devices. The functions include vibration analysis and quantitative debris monitoring systems for transmissions, power assurance checking, low cycle fatigue and thermal creep monitoring for engines, and torque and strain monitoring for complete transmissions and rotor systems. The systems include sensors and algorithms that have been developed very recently, and substantiated by rig tests to deliberate failure, by development flying in arduous conditions, and by application to in-service aircraft. An overview of the development programmes leading to certification of the on-board systems will also be given. The impact of these systems on maintenance policies is also discussed.

TITLE Health and Usage Monitoring Techniques for Greater Safety in Helicopter Operations

INDEX NO. 21HED.37SCT-TED

AUTHOR D.G. Astridge; Westland Helicopters Ltd., United Technologies Corp.

PUBLISHER International Journal of Aviation Safety
DATE September, 1985
DOC TYPE Journal Paper
ABSTRACT

The paper discusses work being done to monitor the integrity of helicopter transmissions during operation. Health monitoring should provide early warning of surface wear modes, a clear rejection signal for surface wear modes, and means of corroborating the indications at the aircraft by maintenance personnel. For transmissions, the primary usage parameter is torque-transmitted, although in instances where rotor loads are transmitted through the gearbox casing, rotor loads and moments may need to be analyzed. Significant advances have been made in gearbox health monitoring technology, particularly in quantitative debris monitoring (i.e., the Tedeco QDM system), and in enhanced vibration signal averaging (i.e., Westland's vibration analysis techniques have demonstrated the ability to detect cracks and fracture modes before they are visible to the eye).

TITLE Helicopter Gear Box Condition Monitoring for Australian Navy

INDEX NO. 22HED.38SCT-TED

AUTHOR K.F. Fraser, C.N. King; Aeronautical Research Laboratories

PUBLISHER Reprinted by AIAA
DATE
DOC TYPE Conference Paper
ABSTRACT

The Aeronautical Research Laboratories has been involved for more than a decade in studies on behalf of, and in the provision of scientific advice to, the Royal Australian Navy on airworthiness matters in respect of the main rotor gear boxes for its Wessex Mk 31B and Sea King Mk 50 helicopters. Work has been undertaken in the two major areas of gear box health and fatigue life usage monitoring. The health monitoring program has included both oil/wear debris analysis and vibration analysis. Significant advances in the area of early failure detection have been achieved in the vibration work. Safe fatigue lives of all gears in the main rotor gear boxes for Wessex and Sea King have been estimated for Australian operating conditions. Prototype equipment developed at these Laboratories and currently fitted in some Sea King helicopters estimates fatigue life usage of gears during flight and is capable of monitoring actual life usage for individual gear boxes.

TITLE Helicopter Health and Safety

INDEX NO. 23HED.39SCT-TED
AUTHOR G. Norris

PUBLISHER Flight International
DATE January, 1990
DOC TYPE Magazine Article

ABSTRACT

The drive to improve the airworthiness of civil helicopters is being tackled on three fronts: design, technology and operations. New helicopters are being developed which embody airliner standards of safety and system redundancy from the first set of designs. Microprocessor-based technology, principally in the area of health and usage monitoring systems (HUMS) and flight data recording (FDR), is being integrated into existing helicopters. Operations are being made safer by revised regulations.

TITLE 10th Helicopter Health Monitoring Advisory Group (HHMAG) Meeting Minutes

INDEX NO. 24HED.40SCT-TED
AUTHOR S.L. James; Helicopter Health Monitoring Advisory Group

PUBLISHER Helicopter Health Monitoring Advisory Group
DATE April, 1989
DOC TYPE Meeting Minutes

ABSTRACT

The minutes include three briefings and two trial updates. The briefings are "AS332 Mk2 Health Monitoring" by M.R. Francois of Aerospatiale, "EH101 Health Monitoring" by Signor Bruno Maino of EHI, and "Review of Rotor System Catastrophic Failures" by Mr. Andrew of MJA Dynamics. For the AS332 trial, seventy vibration recordings and thirty-two oil debris samples had been taken; the first flight of the full HUMS on-board system was delayed. For the S61 trial, the two aircraft involved in the trial would be operational in late June 1989 and the other in August 1989. Also, three thousand hours of monitoring will permit strip evidence to be correlated to SOAP analysis.

TITLE 11th Helicopter Health Monitoring Advisory Group (HHMAG) Meeting Minutes

INDEX NO. 25HED.41SCT-TED

AUTHOR S.L. James; Helicopter Health Monitoring Advisory Group

PUBLISHER Helicopter Health Monitoring Advisory Group
DATE October, 1989
DOC TYPE Meeting Minutes

ABSTRACT

The minutes include four briefings and updates on the S61 trial and the AS333 trial. The briefings are "Application of Expert Systems in Improving Helicopter Airworthiness" by the University of Exeter School of Engineering (Condensed report also included), "HUMS: FAA Update" by J.D. Swihart of FAA Southwest Region, "ROTABS: Rotor Trim And Balance System" by T. Staub, and "RADS" by K. Pipe of Stewart Hughes.

TITLE Helicopter Health Monitoring from Engine to Rotor

INDEX NO. 26HED.42SCT-TED

AUTHOR J.F. Marriott, J.F.M. Kaye; Hawker Siddeley Dynamics Engineering Ltd.

PUBLISHER ASME - Gas Turbine and Aerospace Congress
DATE June, 1988
DOC TYPE Conference Paper

ABSTRACT

Recent tragic accidents have focused attention on the dangers of unmonitored helicopter dynamic assemblies. Methods are available to monitor the entire power train from the engine to the rotor. Apart from the obvious safety advantages, such systems offer the additional benefits of increased availability, a planned maintenance schedule and a reduction in life cycle costs.

Historically, monitoring systems have evolved from isolated processing units, each performing single functions. Hawker Siddeley Dynamics Engineering Ltd, in conjunction with Stewart Hughes Ltd is developing a modular and integrated health and usage monitoring system. After a brief discussion of health monitoring equipment evolution, this paper focuses on the practical application of the techniques required to ensure the health of the modern helicopter.

TITLE Helicopter Operators Forecast Steady Growth into Mid-1990s

INDEX NO. 27HED.43SCT-TED
AUTHOR N.C. Kernstock

PUBLISHER Aviation Week & Space Technology
DATE February, 1990
DOC TYPE Magazine Article
ABSTRACT
The global civil helicopter industry has experienced a rebound, although business has not yet returned to the high levels seen in the late 1970s. Four operators typify those who are achieving success by controlling the growth of existing business and their entry into new markets, as well as exploiting profitable niches. While these companies' operations encompass a wide variety of helicopter missions, three major markets are responsible for most of the growth: the oil industry, police and public service, and medical flight service.

TITLE Hoverview - More HUM Trials Due

INDEX NO. 28HED.44SCT-TED
AUTHOR Helicopter World

PUBLISHER Helicopter World
DATE January-March, 1990
DOC TYPE Magazine Article
ABSTRACT
A series of trials, due to start in February 1990, on North Sea helicopters represents a continuation of the UK Civil Aviation Authority's thrust to establish the utility and effectiveness of health and usage monitoring (HUM) in service. British International Helicopters (BIH) will conduct the trials on two of its Sumburgh-based S61N helicopters. The trials involve a total of 1,100 hours flying time over twelve to fifteen months. The HUM equipment will analyze data from a range of sensors to detect faults in their very early stages. Sensors include debris monitors, accelerometers, and a fixed optical tracker for accurate sensing of rotor track and lag. The on-board HUM processor can also derive high-level safety and maintenance conclusions.

TITLE The Integration of Health Monitoring Techniques for Helicopter Gearboxes

INDEX NO. 29HED.45SCT-TED

AUTHOR Comm. M.J.D. Brougham; Royal Navy MoD Directorate of Helicopter Proj.
P. Gadd; Naval Aircraft Materials Laboratory, RNAY Fleetlands

PUBLISHER The City University - 11th European Rotorcraft Forum

DATE September, 1985

DOC TYPE Conference Paper

ABSTRACT

This paper discusses the use of a combination of health monitoring techniques to provide comprehensive coverage of possible failure modes in a typical transmission gearbox. From experience gained in research and development work sponsored by the UK Ministry of Defence in recent years, the paper explores the relative value of conventional status parameters such as oil level, pressure and temperature, together with the newer techniques of wear debris and vibration analysis.

The use of health monitoring techniques in a matrix to provide both early warning of failure and diagnostic information is considered, as well as the effect of design features such as transmission configurations, oil filtration standards and filter bypass arrangements. The problems of data collection and processing are also discussed.

The development of the Anglo Italian EH 101 Health and Usage Monitoring System is used to illustrate the process of sensor location, validation of processor algorithms and the planning to achieve full system certification.

TITLE KRASH Analysis Correlation with the Bell ACAP Full-Scale Aircraft Crash Test

INDEX NO. 30HED.46SCT-TED

AUTHOR J.D. Cronkhite; Bell Helicopter Textron
L.T. Mazza; Aviation Applied Technology Directorate, U.S. AVSCOM

PUBLISHER American Helicopter Society - National Technical Specialists Meeting

DATE October, 1988

DOC TYPE Conference Paper

ABSTRACT

The Bell ACAP aircraft, developed under the U.S. Army's Advanced Composite Airframe Program, was designed to meet the Army's stringent crash survivability requirements using the KRASH analysis combined with testing of critical energy-absorbing structural components. The full-scale aircraft was crash tested at the Impact Dynamics Facility of NASA Langley Research Center and successfully demonstrated that it provided crash protection for the occupants and fully met the ACAP crash requirements. The actual test condition was somewhat more severe than planned. Also, the onboard acceleration data was lost during the test and comparisons of the test results with the KRASH simulation had to be conducted using high speed photo motion analyses and post test measurements. For comparison purposes the KRASH analysis was updated after the test to represent the actual test condition and to incorporate unexpected damage that had occurred to a tail gear fitting and the engine deck, and were not included in the original analysis. Comparisons of the KRASH analysis and test showed good agreement and verified that KRA5H was a viable analytical tool for the design of composite airframe structures for crash impact.

TITLE Mastering a Complicated Beast

INDEX NO. 31HED.47SCT-TED

AUTHOR M. Hodges; Georgia Institute of Technology

PUBLISHER Research Horizons
DATE Spring, 1990
DOC TYPE Magazine Article

ABSTRACT

At the Center of Excellence for Rotary Wing Aircraft Technology (CERWAT) at the Georgia Institute of Technology, fourteen faculty and about thirty graduate researchers address basic research questions that U.S. industrial and government laboratories are not equipped to handle. The research at CERWAT centers on four key areas: aerodynamics, aeroelasticity, structures and materials, and flight controls and mechanics. A key discipline for rotorcraft is understanding turbulant flow. From the point of view of the rotor, one must understand the motion of vortices that spin off the blade, and from the point of view of aeroelasticity, one must understand the forces exerted by the turbulent downflow on the airframe. The researchers at CERWAT make use of a laser Doppler wind tunnel in conjunction with advanced software models. The software models are spreading out into industrial use.

Another effort has been to model the reactions of the pilot. For this purpose, two types of models are in use: the linear model or 'autopilot', and the nonlinear 'shooting' model. The nonlinear model will regress time if it crashes, and 'take another shot' at controlling the aircraft. Other efforts involve modelling composite materials (e.g. a blade that twists when it stretches) and advanced control systems involving feedback.

TITLE MDHC's Enhanced Diagnostics System, A Unique and Comprehensive Approach to Structural Monitoring

INDEX NO. 32HED.48SCT-TED

AUTHOR J. Harrington III, D. Chia, J. Neff; McDonnell Douglas Helicopter Company

PUBLISHER Reprinted by AIAA
DATE
DOC TYPE Conference Paper

ABSTRACT

Currently in the helicopter industry, structural component lives and inspection criteria are established by damage tolerance or safe life methods. An accurate determination of the loading spectrum of the component is required for both methodologies. Structure monitoring of aircraft through the use of flight data recorder technology could substantially reduce the uncertainties in the load spectrum used in component life analysis. McDonnell Douglas Helicopter Company has developed a multi-functional flight data recorder system for the Army's AH-64A Apache Helicopter. One of the primary functions of the Enhanced Diagnostic System (EDS) is to obtain operational loads data. EDS structural monitoring is unique because it uses aircraft mission subsystems data as well as strain gage data to monitor loads and aircraft usage. The purpose of this paper is to describe the EDS structural monitoring approach and to propose a methodology for using the EDS structural loads data in a comprehensive Structural Integrity Program.

TITLE The Modularity of the Health and Usage Monitoring System

INDEX NO. 33HED.49SCT-TED

AUTHOR P.D. Baker; Smiths Industries Aerospace & Defence Systems

PUBLISHER Aeronautic & Astronautic Assoc. of France - 13th Europ. Rotorcraft Forum
DATE September, 1987
DOC TYPE Conference Paper

ABSTRACT

The Health and Usage Monitoring System has functional flexibility or modularity by application, whilst the core of the system, the Health and Usage Monitor, is modular by design and function. It is possible by these means to produce a system which is sufficiently versatile to meet the needs of the rotorcraft operator, the requirements of the rotorcraft and engine manufacturers, and those of the certifying authorities. The purpose of this paper is to outline the range of facilities and functions available at this time for health and usage monitoring.

Data can be accepted by the system from any type of sensor. These data are validated before compression and storage, for subsequent examination, or for immediate utilization in a variety of functions. The functions themselves can cover the power plant, airframe, transmission and rotor. Experience in the development and application of the system has been gained to a greater or lesser extent in a variety of fixed and rotary winged aircraft, in both civil and military applications; it is this which is the basis of the paper.

TITLE Osprey's VSLED: Rewriting the Maintenance Manual

INDEX NO. 34HED.50SCT-TED

AUTHOR E.W. Bassett;

PUBLISHER Rotor & Wing International
DATE June, 1988
DOC TYPE Magazine Article

ABSTRACT

The Vibration, Structural Life and Engine Diagnostic System (VSLED) is the aircraft health-monitoring system under development for the V-22 Osprey. VSLED consists of an airborne unit and a sensor network. The airborne unit is built around a MIL-STD-1750 processor and two co-processors. The sophisticated and extensive sensor network puts VSLED in touch with engine and airframe components.

TITLE The On-Condition Qualification of the Trailing Edge Area of the UH-1H Metal Main Rotor Blade

INDEX NO. 35HED.51SCT-TED

AUTHOR B. Dickson; Bell Helicopter Textron
R. Arden; Aviation Applied Technology Directorate, U.S. AVSCOM

PUBLISHER American Helicopter Society - National Specialists Meeting

DATE October, 1988

DOC TYPE Conference Paper

ABSTRACT

A program has been conducted by Bell Helicopter Textron, Inc. (BHTI), under contract to AVSCOM engineering, to establish an on-condition replacement status for the UH-1H metal main rotor blade considering fatigue cracking along the trailing edge. Two test specimens constructed from service-returned blades were used to generate crack growth data. Innovative approaches used in the test included application of a multistep spectrum of beamwise, chordwise, and torsional loads derived from the UH-1H operational spectrum to simulate a 2-hour flight. Application of test loads included the superposition of the significant 1/rev and 7/rev chordwise loads to realistically account for the dynamic response of the blade in flight. The paper presents details of the derivation of the crack growth test load spectrum, details of the test, and crack growth data generated that were subsequently used to establish a safe inspection interval.

TITLE Qualification and Fleet Introduction of the AH-1T Flight Loads and Usage Monitor

INDEX NO. 36HED.52SCT-TED

AUTHOR C.G. Schaefer, Jr.; Helicopter Loads and Dynamics, Naval Air Command

PUBLISHER Reprinted by AIAA

DATE

DOC TYPE Conference Paper

ABSTRACT

The U.S. Navy is currently assessing the validity of its present fatigue methodology for rotary wing aircraft. NAVAIR is now involved in a fleet usage survey that will attempt to collect a sizable database to evaluate the current attack helicopter usage spectrum. The survey includes the design and installation of an instrumentation system that monitors flight environmental loads and operational mission usage of eight fleet Marine AH-1T (TOW) attack helicopters. This paper addresses that flight test effort, some of the problems encountered and the introduction of the system into the fleet.

TITLE Qualification Testing of AH64 Fly By Wire Back Up Control System (BUCS)

INDEX NO. 37HED.53SCT-TED
AUTHOR S.S. Osder; McDonnell Douglas Helicopter Company

PUBLISHER Reprinted by AIAA
DATE
DOC TYPE Conference Paper
ABSTRACT
The AH64 Helicopter's Fly By Wire Back Up Control System was qualified using a combination of tests performed on the aircraft and in a closed loop validation facility. The Back Up Fly By Wires System concept is described and the test procedures used to qualify that system are reviewed. Some key technical issues relating to the control logic used to monitor system health and to detect the conditions requiring automatic Back Up Control engagement are discussed.

TITLE Rotorcraft Trends - Part 2 Requirements and Monitoring

INDEX NO. 38HED.54SCT-TED
AUTHOR T. Ford

PUBLISHER Aircraft Engineering
DATE December, 1985
DOC TYPE Magazine Article
ABSTRACT
A Civil Aviation Authority (CAA) working group on helicopter health monitoring concluded that for future helicopter designs, the transmissions and rotor systems would benefit most from the use of health monitoring techniques. Three other areas were also identified as important areas for effective monitoring: flight control systems, structure, and engines and fuel systems. Requirements and monitoring recommendations are made for each of these five areas.

TITLE Sikorsky Adopts Cautious Approach to Japanese Civil Helicopter Market

INDEX NO. 39HED.55SCT-TED

AUTHOR

PUBLISHER Aviation Week & Space Technology

DATE February, 1990

DOC TYPE Magazine Article

ABSTRACT

Although the Japanese have identified a need for about 3,300 heliports and 600 helicopters over the next 20-30 years (to ease the transportation network gridlock), three main hinderances have prompted Sikorsky Aircraft to exercise caution in pursuing the Japanese civil helicopter market. First, Japan has complex and rigid helicopter certification and flight regulations. Second, the national government recently implemented tax codes that will soon make helicopter ownership less attractive. The third and most important reason is that Japan has been experiencing, and for the foreseeable future, will continue to experience a chronic shortage of trained helicopter pilots.

TITLE Simulator Evaluation of Instructional and Design Features for Training Helicopter Shipboard Landing

INDEX NO. 40HED.56SCT-TED

AUTHOR D.J. Sheppard, S.A. Jones, D.P. Westra; Essex Corporation
J.J. Madden; Naval Training Systems Center

PUBLISHER Human Factors Society - Proceedings of 32nd Annual Meeting

DATE 1988

DOC TYPE Conference Paper

ABSTRACT

The effects of four instructional issues and one simulator design feature for training helicopter shipboard landing on small ships were tested in the Vertical Take-off and Landing Simulator (VToL) at the Visual Technology Research Simulator (VTRS), Naval Training Systems Center. They were: (1) field of view (VTRS versus a test field of view), (2) task chaining (segmented backward chaining versus whole task training), (3) augmented cueing (augmented cueing versus no augmented cueing), (4) length of training (18, 27, and 36 trials), and (5) the timing of seastate introduction (early versus late). The experiment utilized an in-simulator transfer-of- training paradigm in which pilots who were not proficient in the helicopter shipboard landing task were trained under one of several experimental conditions, then tested on the transfer condition (that represented maximum realism) in the simulator. Thirty-two pilots each completed a total of 54 trials (36 training, 18 transfer). Pilots were tested in the transfer condition (six trials) after their 18th, 27th, and 36th training trial. Of the experimental instructional issues, task chaining had the largest effect, with better performance in all segments of the task for pilots who were trained with the backward-chaining sequence, than for pilots who received whole task training. Augmented cueing did not yield the transfer performance anticipated. Seastate introduction had no effect on performance. Field of view had some marginal effects on vertical performance in the hover, with better performance for pilots who were trained with the combination VTRS field-of-view and backward-chaining. Results suggest a diminished rate of learning after 33 simulator trials (includes 27 training trials and six transfer trials of the first probe).

TITLE Strengthening the Weak Link of Fatigue Qualification

INDEX NO. 41HED.57SCT-TED

AUTHOR K.M. Rotenberger; U.S. Army Aviation Systems Command

PUBLISHER

DATE

DOC TYPE Conference Paper

ABSTRACT

The "weak link" in the fatigue substantiation process is the aircraft usage spectrum. In recognition of this, the Army is conducting several programs designed to better account for the actual usage of Army helicopters. A pilot survey program was conducted for the AH-1 and UH-1 systems and produced updated spectra that incorporated new missions and tactics previously unaddressed. Many programs involving Flight Data Recorders are currently underway. They are designed to record the data necessary to continuously define the condition of an aircraft in flight. Once incorporated, this will allow the Army to monitor and update usage spectra as necessary and thereby enhance the "weak link" of the fatigue substantiation process.

TITLE UH-60 Flight Data Replay and Refly System State Estimator Analysis

INDEX NO. 42HED.58SCT-TED

AUTHOR M. Whorton; University of Alabama

PUBLISHER AIAA - 28th Aerospace Sciences Meeting

DATE January, 1990

DOC TYPE Conference Paper

ABSTRACT

Research currently underway at The University of Alabama Flight Dynamics Lab (UAFDL) investigates concepts for implementation of a ground-based UH-60 Flight Data Replay and Refly System (UH-60 FDRRS). A variation of a Linearized Extended Kalman filter is implemented which utilizes a mathematical model of the UH-60 to accurately re-create a UH-60 helicopter flight based on flight measurements. Essential in this paper is the development of the UH-60 mathematical model, an experimental verification of the Kalman filter implementation, and an experimental evaluation of filter sensitivity to initial condition errors, measurement sample rate reductions, and model parameter variations. Results indicate that vehicle dynamics are represented with sufficient fidelity by the UK-A mathematical model for both filter design and piloted simulation, providing a replay and a refly capability. Experimental analysis of the Kalman filter indicates that the current filter exhibits a robust tracking ability for low measurement sample rates; demonstrates relatively fast, stable convergence in the presence of initial condition errors; yet manifests a notable performance degradation due to weight variations.

TITLE U.S. Army Flight Condition Monitoring

INDEX NO. 43HED.59SCT-TED

AUTHOR R.L. Buckner, D.J. Merkley; Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVSCOM)

PUBLISHER

DATE

DOC TYPE Conference Paper

ABSTRACT

The Flight Condition Monitoring (FCM) method of acquiring operational usage data is presented as it was developed from US Army helicopter service usage programs from 1964 to present. The importance of incorporating operational usage data in fatigue design approaches, such as Safe-Life and Damage Tolerance, is discussed with emphasis on the establishment of dynamic component fatigue lives. The Army's service usage programs are critically reviewed to determine areas of sensitivity in establishing design mission spectra for rotary-winged aircraft. The feasibility of utilizing FCM with state-of-the-art microprocessor recorder technology on future in-service programs is presented with suggested unified approaches to mission spectrum development on current and future helicopter systems.

TITLE Vibration Analysis for Detection of Bearing and Gear Faults Within Gearboxes: An Innovative Signal Processing Approach

INDEX NO. 44HED.60SCT-TED

AUTHOR R.C. Kemerait, G.W. Pound, L.J. Owiesny; ENSCO, Inc.

PUBLISHER

DATE

DOC TYPE Conference Paper

ABSTRACT

The principal purpose of this research was to investigate the possibility of enhancing the early detection of gear and bearing problems in helicopter gearboxes utilizing more sophisticated signal processing techniques. Additional considerations were the applicability of these improvements to routine helicopter maintenance and use as an aid for in-flight readiness. The selected research dealt with the processing of acceleration data collected from Navy TH-1L helicopter test bed. The aircraft was strapped down with the main rotor removed for safety reasons and the tail rotor left on to load the 42 degrees gearbox being investigated. The signal processing research dealt principally with the potential improvements to be gained by utilizing the complex and cosine squared cepstrum techniques. Considerable apparent gains in performance were achieved by a combination of the traditional and unique employments of these cepstral techniques. Many other signal processing features were investigated and reported as by-products of this research.

TITLE Artificial Intelligence Techniques for Ground Test Monitoring of Rocket Engines

INDEX NO. 01RED.61SCT-TED

AUTHOR M. Ali, U.K. Gupta; Center for Advanced Space Propulsion, University of Tennessee Space Institute

PUBLISHER American Institute of Aeronautics and Astronautics, Inc.

DATE July, 1990

DOC TYPE Conference Paper

ABSTRACT

The goal of the ongoing research described in this paper is to develop an expert system which can detect anomalies in Space Shuttle Main Engine (SSME) sensor data significantly earlier than the redline algorithm currently in use. In the training of such an expert system we have focused on two approaches which are based on low frequency and high frequency analyses of sensor data. Both approaches are being tested on data from SSME tests and their results compared with the findings of NASA and Rocketdyne experts. Our prototype implementations have detected the presence of anomalies earlier than the redline algorithms that are in use currently. It therefore appears that our approaches have the potential of detecting anomalies early enough to shut down the engine or take other corrective action before severe damage to the engine occurs.

TITLE Comparison of Nonlinear Smoothers and Nonlinear Estimators for Rocket Engine Health Monitoring

INDEX NO. 02RED.62SCT-TED

AUTHOR B.K. Walker, E.T. Baumgartner; Health Monitoring Technology Center for Space Propulsion Systems, University of Cincinnati

PUBLISHER American Institute of Aeronautics and Astronautics, Inc.

DATE July, 1990

DOC TYPE Conference Paper

ABSTRACT

A new nonlinear, real time smoothing algorithm is applied to the problem of estimating some of the parameters that describe the dynamics of a reusable space propulsion system, in particular parameters that are likely to change when engine degradations occur. The results are compared to those from a nonlinear filtering algorithm based upon the extended Kalman filter. The Space Shuttle Main Engine (SSME) operating at its 100% Rated Power level is used as the baseline propulsion system with the filter and smoother designs based upon a reduced order dynamic model of the SSME. The data used to drive the algorithms is generated by a high fidelity transient simulation of the SSME with small magnitude random dither signals applied to the fuel side control valves and with substantial random noise added to the measured outputs. The results indicate the smoother provides substantial improvement over the filter in terms of parameter estimation accuracy. However, both algorithms are not always able to track the correct parameter values when changes in these values representing engine degradations are introduced in the simulation that produces the data. The paper concludes with an examination of the effect of measurement biases on the parameter estimation performance of the smoother and a method to compensate these effects.

TITLE Condition Monitoring of Liquid Rocket Engines Using Statistical Process Control

INDEX NO. 03RED.63SCT-TED

AUTHOR E. Royer, D. Wolting; Aerojet TechSystems Company

PUBLISHER American Institute of Aeronautics and Astronautics, Inc.
DATE July, 1989
DOC TYPE Conference Paper and Slides

ABSTRACT
This paper discusses the application of statistical process control methodology to problems of engine performance and condition monitoring. These methods include simple X-bar, R, and Cumulative Sum Control Charts. A case study is presented, where these techniques are applied to evaluate the performance of liquid rocket engines over time. The results show that these methods can be very effective aids in analyzing flight data and in confidently developing performance predictions for future missions.

A multivariate control chart is also presented for summarizing the condition of liquid rocket engines. The method combines numerous measurements into a single statistic which characterizes overall engine status. Tests of significance based on this statistic are shown to identify faults or anomalies which would otherwise go undetected. Diagnostic procedures using multivariate methods are discussed, as are ways to reduce both Type I and Type II errors in engine condition monitoring applications.

TITLE Cost-Benefit Modeling for Rocket Engine Condition Monitoring Systems

INDEX NO. 04RED.64SCT-TED

AUTHOR C.J. Mcisl; Rocketdyne Division, Rockwell International

PUBLISHER American Institute of Aeronautics andAstronautics, Inc.
DATE July, 1989
DOC TYPE Conference Paper

ABSTRACT
Condition Monitoring Systems (CMS) for rocket engines may contribute significantly to future decreased launch costs, due to improvements in the overall reliability of propulsion systems and streamlined pre-launch and refurbishment processes. This paper discusses a methodology for assessing the costs and benefits of rocket engine CMS for future launch vehicles. The methodology is based on net life cycle cost savings for the total vehicle and payload system. It considers the actual cost of CMS, the unreliability penalties of the CMS as well as its beneficial effects on reducing operational costs and increasing overall engine reliability.

Emphasis of the work reported in this paper is on engine reliability improvements and decreased costs for a launch cycle. The reliability modeling was performed using a simulation method based on fault trees for two key component groups, i.e., turbopump and Main Combustion Chamber with nozzle. Changes in launch cycle costs were determined using a Markov Chain approach which accounts for the cost of engine-caused launch vehicle failures. The methodologies are described, preliminary parametric results presented for reusable engines and cost drivers discussed.

TITLE Cost Effectiveness Perspectives for Launch Vehicle Health Monitoring Systems

INDEX NO. 05RED.65SCT-TED

AUTHOR R.L. Puening; Martin Marietta Astronautics Group

PUBLISHER American Institute of Aeronautics and Astronautics, Inc.
DATE July, 1990
DOC TYPE Conference Paper

ABSTRACT

This paper describes methodologies to quantitatively determine the cost effectiveness of health monitoring systems for different types of launch vehicles and launch vehicle stages. The interaction of health monitoring with other programmatic element cost saving measures is described. Individual elements of cost saving benefits and penalties of health monitoring systems as applied to launch vehicles are assessed utilizing a health monitoring cost model spreadsheet tool developed by the author.

TITLE Development of a Health Monitoring Algorithm

INDEX NO. 06RED.66SCT-TED

AUTHOR E. Nemeth, A.M. Norman Jr.; Rocketdyne Division, Rockwell International

PUBLISHER American Institute of Aeronautics and Astronautics, Inc.
DATE July, 1990
DOC TYPE Conference Paper

ABSTRACT

An algorithm has been developed using fourteen measurements of the Space Shuttle Main Engine (SSME) rocket engine that in many cases provides significantly better performance (detection of damage and then shutdown) than existing redline-type algorithms.

Essentially, the algorithm has permissible zones for functions of combinations of the variables, rather than just limits on the values considered independently. The limit functions are developed ad hoc rather than using some estimation-control oriented technique.

TITLE Diagnostic Needs of the Space Shuttle Main Engine

INDEX NO. 07RED.67SC-TED

AUTHOR RR. Teeter, A.E. Tischer, R.C. Glover, B.A. Kelley; Battelle Columbus Laboratories

PUBLISHER Battelle Columbus Laboratories
DATE 1984
DOC TYPE Technical Paper

ABSTRACT
A study is being conducted for NASA on potential diagnostic system improvements to the Space Shuttle Main Engine (SSME). This paper reports midterm progress including : (1) the results of a failure mode review identifying key diagnostic needs; (2) the results of a survey of diagnostic techniques that might be applied to the SSME; and (3) application to the SSME of a Battelle developed tool (the Failure Information Propagation Model, or FIPM) for analysis of diagnostic needs. It is concluded that opportunities for significantly improved diagnostics exist in a number of areas. Future plans are described that are directed toward development of a diagnostics strategy and design recommendations for an improved diagnostic system for the SSME.

TITLE An Expert System for Fault Diagnosis in a Space Shuttle Main Engine

INDEX NO. 08RED.68SCT-TED

AUTHOR M. Ali, U. Gupta; University of Tennesse Space Institute

PUBLISHER American Institute of Aeronautics and Astronautics
DATE July, 1990
DOC TYPE Conference Paper

ABSTRACT
The detection and diagnosis of SSME faults in an early stage is important in order to allow enough time for fault preventive or corrective measures. Since most of the faults in a complex system like SSME develop rapidly, early detection and diagnosis of faults is critical for the survival of space vehicles. We have designed an expert system for automatic learning, detection, identification, verification and correction of anomalous propulsion system operations. This paper describes an innovative machine learning approach which is employed for the automatic tracking of this expert system.

TITLE Health Monitoring System for the SSME: Fault Detection Algorithms

INDEX NO. 09RED.69SCT-TED

AUTHOR S. Tulpule, W.S. Galinaitis; United Technologies Research Center

PUBLISHER American Institute of Aeronautics and Astronautics
DATE July, 1990
DOC TYPE Conference Paper

ABSTRACT
A Health Monitoring System (HMS) Framework for the Space Shuttle Main Engine (SSME) has been developed by United Technologies Corporation (UTC) for the NASA Lewis Research Center. As part of this effort, fault detection algorithms have been developed to detect the SSME faults with sufficient time to shutdown the engine. These algorithms have been designed to provide monitoring coverage during the startup, mainstage and shutdown phases of the SSME operation. The algorithms have the capability to detect multiple SSME faults, and are based on time series, regression and clustering techniques. This paper presents a discussion of candidate algorithms suitable for fault detection followed by a description of the algorithms selected for implementation in the HMS and the results of testing these algorithms with the SSME test stand data.

TITLE Health Monitoring System for the SSME: Hardware Architecture Study

INDEX NO. 10RED.70SCT-TED

AUTHOR J.K. Kamenetz; Hamilton Standard Division of United Technologies
M.W. Hawman, S. Tulpule; United Technologies Research Center
PUBLISHER American Institute of Aeronautics and Astronautics
DATE July, 1990
DOC TYPE Conference Paper

ABSTRACT
This paper presents a hardware architecture for a Health Monitoring System (HMS) for the Space Shuttle Main Engine (SSME). The architecture study was conducted in conjunction with a NASA sponsored program to develop a framework for SSME HMS for ground test and, potentially, flight applications. The function of the ground based HMS was two fold: protect engines during ground test and provide a test bed for HMS development. The flight system would potentially serve as a maintenance aid and as a safety feature. The requirements of the program were to use as much of the existing controller and facility instrumentation as possible and to utilize existing or near term technologies. The HMS was intended to be designed, developed and qualified for ground use within 5 years. Fundamentally, the HMS design should not preclude flight based operation.

The paper follows a defined conceptual design process. The requirements for both systems are both stated and analyzed. A multi-processor, distributed, VME system is envisioned for the ground test hardware. By repackaging the boards, the same concept is shown to be usable for the flight system. The paper concludes with an analysis of weight, power and reliability with respect to variations in functionality.

TITLE HERMES Propulsion Subsystem On-Board Diagnostic Monitoring and Control

INDEX NO. 11RED.71SCT-TED

AUTHOR N. Cornu, G. Gerbes; Societe Europeenne de Propulsion, Space and Defence Group

PUBLISHER American Institute of Aeronautics and Astronautics
DATE July, 1990
DOC TYPE Conference Paper

ABSTRACT
After a description of the HERMES propulsion requirement, physical characteristics and basic principles selected for the spacionics, this paper is intended, in a second part, to set up the objectives of the on board diagnostic monitoring and control, the monitoring concept and the monitoring method to be applied to the HERMES propulsion subsystem. The resultant measurement points with their data requirements and the new technological developments needed are described in the third part of this paper.

TITLE The History and Future of Safety Monitoring in Liquid Rocket Engines

INDEX NO. 12RED.72SCT-TED

AUTHOR A. Norman, I. Cannon, L. Asch; Rockwell International, Rocketdyne Division

PUBLISHER American Institute of Aeronautics and Astronautics
DATE July, 1989
DOC TYPE Conference Paper

ABSTRACT
One of the major advantages of liquid rocket engines is their ability to modify operating conditions during a firing in order to prevent failures which might otherwise result in loss of the mission or damage to test facilities. The simplest and most common form of modification is shutdown, but transitioning to a more benign condition for a detected problem is likely to become more common in future engines as new and more powerful control hardware and software become available. In order to take advantage of this capability, monitoring systems must be able to detect unsafe conditions and signal the control system to take the appropriate actions. This paper will discuss the history and development of these safety monitoring systems to the present day, what can be expected in the foreseeable future, and how the past history can affect these expectations.

TITLE Integrated Health Monitoring Approaches and Concepts for Expendable and Reusable Space Launch Vehicles
INDEX NO. 13RED.73SCT-TED

AUTHOR J.G. Johnson; General Dynamics Space Systems Division

PUBLISHER American Institute of Aeronautics and Astronautics
DATE July 1990
DOC TYPE Conference Paper

ABSTRACT
To support the high launch rates that are projected for space launch vehicles in the 1990s and to reduce current launch system operations costs, test and checkout tasks will have to be accomplished in a more cost-effective and operationally efficient manner. This paper will determine health monitoring approaches and concepts for expendable and reusable space launch vehicles, and provide a definition and architecture for integrated health monitoring. Expendable space launch vehicle flight history data is also presented to further understand the types of anomalies that have occurred on past space launch systems. A vehicle data architecture is also presented for reviewing data and obtaining the maximum amount of information that is available onboard a space launch vehicle system. Information is also presented concerning the technology issues for a fully integrated health monitoring system, as well as the evolutionary trend that is occurring between the ground support equipment and airborne areas.

TITLE Neural Network Approach to Space Shuttle Main Engine Health Monitoring

INDEX NO. 14RED.74SCT-TED

AUTHOR B. Whitehead, H. Ferber, M. Ali; Center for Advanced Space Propulsion, University of Tennesse Space Institute
PUBLISHER American Institute of Aeronautics and Astronautics
DATE July, 1990
DOC TYPE Conference Paper

ABSTRACT
A neural network was trained to distinguish anomalies in Space Shuttle Main Engine sensor data from noisy normal steady-state sensor data. Power spectra of successive windows of individual sensor data were presented to a neural network using Kohonen's topological feature map training algorithm. The trained network for each sensor was then tested to determine if it would detect anomalies in the sensor data, and if so, the time at which the anomaly would be detected. Power spectra from a few hundred seconds of actual test data from NASA tests 901-364 and 904-044 were used to test the network. In both cases, the neural network detected the onset of anomalous engine behavior at approximately the same time within each test as the onset times reported by NASA and Rocketdyne experts in their post-test analyses.

TITLE Neural Network Pattern Recognizer for Detection of Failure Modes in the SSME

INDEX NO. 15RED.75SCT-TED

AUTHOR H. Luce, R. Govind; NASA, Health Monitoring Technology Center, University of Cincinnati
PUBLISHER American Institute of Aeronautics and Astronautics
DATE July 1990
DOC TYPE Conference Paper

ABSTRACT
A system for diagnosis of emergent performance degradations and failure modes in the Space Shuttle Main Engine (SSME) is described. This system looks at the SSME as a collection of subassemblies, and uses time signature data, from sets of parameters arising from sensors local to each subassembly, to compose patterns to be analyzed. A hybrid architecture is used: The first processing layer consists of ART2 (Adaptive Resonance Theory) neural networks, one ART2 network per subassembly; the second layer consists of CAM (Content Addressable Memory) networks, one per subassembly; and the final layer is a backpropagation neural network, which processes data from all of the CAM networks. A prototype system, encompassing only the High Pressure Fuel Turbopump (HFTP) is presented. The long-term goal of this work is to create a system using the above architecture to ensure that the SSME remains in a state of "health", by creating a feedback loop incorporating operating parameter controls, subassemblies, sensors, and the neural network system.

TITLE Prelaunch Expert System for Space Shuttle Propulsion System Health Monitoring

INDEX NO. 16RED.76SCT-TED

AUTHOR J. Engle, D. Bogart, J. Marinuzzi; Rockwell International Corporation, Space Transportation Systems Division
PUBLISHER American Institute of Aeronautics and Astronautics
DATE July, 1990
DOC TYPE Conference Paper

ABSTRACT
The Prelaunch Expert System (PLES) is a ground-based real-time expert system used to monitor sensors for each Space Shuttle subsystem and identify launch commit criteria (LCC) violations, their causes, and suggested courses of action. This expert system will reduce the workload and enhance the performance of engineers who monitor large amounts of data and will speed up their reaction time to potential problems. In addition, it can preserve valuable Shuttle program knowledge that might otherwise be lost with the retirement or transfer of senior personnel. The Building of the system was driven by the needs of the Mission Support community and has therefore found a high degree of acceptance among its intended end users.

TITLE Progress Toward an Automated Visual Inspection System

INDEX NO. 17RED.77SCT-TED

AUTHOR P. Coleman, S. Nelson, J. Maram, A. Norman; Rockwell International, Rocketdyne Division
PUBLISHER American Institute of Aeronautics and Astronautics
DATE July, 1990
DOC TYPE Conference Paper

ABSTRACT
This paper discusses current trends in the automation of visual inspections for reusable rocket engine systems. The application of automated inspection methods for between flight maintenance and manufacturing is discussed. In addition, the application of vision processing to images acquired by current methods of visual inspection is examined.

TITLE Rocket Engine Diagnostics Using Neural Networks

INDEX NO. 18RED.78SCT-TED

AUTHOR B. Whitehead, E. Kiech, M. Ali; Center for Advanced Space Propulsion, University of Tennessee Space Institute
PUBLISHER American Institute of Aeronautics and Astronautics
DATE July, 1990
DOC TYPE Conference Paper

ABSTRACT
Two problems in applying neural networks to fault detection and identification are (1) the complexity of the sensor data to fault mapping to be modeled by the neural network, which implies difficult and lengthy training procedures; and (2) the lack of sufficient training data to adequately represent the very large number of different types of faults which might occur. Methods are derived and tested in an architecture which addresses these two problems. First, the sensor data to fault mapping is decomposed into three simpler mappings which perform sensor data compression, hypothesis generation, and sensor fusion. Event training is performed for each mapping separately. Secondly, the neural network which performs sensor fusion is structured to detect new unknown faults for which training examples were not presented during training. These methods were tested on a task of fault detection and identification in the Space Shuttle Main Engine (SSME). Results indicate that the decomposed neural network architecture can be trained efficiently, can identify faults for which it has been trained, and can detect the occurrence of faults for which it has not been trained.

TITLE Role of Microstructural Sensors for Space Propulsion Health Monitoring

INDEX NO. 19RED.79SCT-TED

AUTHOR H.T. Henderson, W. Hsieh; Department of Electrical and Computer Engineering, University of Cincinnati

PUBLISHER American Institute of Aeronautics and Astronautics
DATE July, 1989
DOC TYPE Conference Paper

ABSTRACT
The University of Cincinnati was assigned one of the new NASA Research Centers through a national competition held last year. The area of research here is health and condition monitoring for space propulsion. This area of research is composed of five major subsets: materials modeling; algorithms and control; structural dynamics; flow and propulsion; and sensors.

It is the purpose of this paper to broadly describe the sensors thrust, with an example or two, in order to provide a perspective of the direction and possibilities of this effort. Most specifically, a microflowsensor will be described to illustrate the power of "micromachining" for creation of miniature, smart, affordable and reliable sensors which might be placed in locations where parameter monitoring has been previously impossible.

The microsensors and semiconductor microstructures group is now working primarily with mechanical structures at the mil (thousandths of an inch) level, but with our optical and electron beam facilities and our new nanostructures lab, we are set for dimensional progress over the coming decade.

TITLE Selection of Monitoring Techniques for a Liquid Propellant Rocket Engine

INDEX NO. 20RED.80SCT-TED

AUTHOR E.P. Jurado, J.B. Shade, M.A. Weise; Pratt & Whitney

PUBLISHER American Institute of Aeronautics and Astronautics
DATE July, 1990
DOC TYPE Conference Paper

ABSTRACT
Methodology for selecting a liquid propellant rocket engine condition monitoring system has been developed as part of the Rocket Engine Condition Monitoring System (RECMS) program under contract from the United States Air Force. This paper describes the development and use of procedures, which evaluate gas generator rocket engine failure modes and associated costs to select monitoring techniques for fault detection and the prevention of fault propagation. An expert system computer program has been developed to select an optimum health monitoring system based on potential life cycle savings. This methodology determines the effects of incorporating an engine monitoring system on costs associated with catastrophic future, mission scrub, launch delay, scheduled and unscheduled maintenance action, ground support equipment, engine shutdown, sensor false-flag, algorithm development, and development and production of monitoring techniques. The health monitoring system identified by these methods establishes the required sensors, algorithms, ground support equipment, and signal processors along with the failure modes and engine parameters that become monitored with their selection. Implementing this methodology will result in improvements in both mission success reliability and system life cycle cost.

TITLE Validation Requirements for a Rocket Engine Control and Monitoring System

INDEX NO. 21RED.81SCT-TED

AUTHOR A.M. Norman, Jr., J. Maram, A. Weiss; Rockwell International, Rocketdyne Division

PUBLISHER American Institute of Aeronautics and Astronautics
DATE July, 1990
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ABSTRACT

This paper discusses the requirements for a validation system for rocket engine Control and Monitoring Systems (CMS) and why one is needed in the near term. There is an implicit assumption that although failures (perhaps multiple failures) are a probabilistic outcome, the consequence of failure must be a well-known deterministic function, mainly for political reasons. The proposed solution is an engine simulation program sufficiently sophisticated to model the failure modes of interest.

TITLE Analysis of Airframe/Engine Interactions - An Integrated Control Perspective

INDEX NO. 01TEC.82SCT-TED

AUTHOR D.K. Schmidt, J.D. Schierman; Arizona State University
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PUBLISHER American Institute of Aeronautics and Astronautics, Inc.
DATE July, 1990
DOC TYPE Conference Paper

ABSTRACT
Techniques for the analysis of the dynamic interactions between airframe/engine dynamical systems are presented. Critical coupling terms are developed that determine the significance of these interactions with regard to the closed loop stability and performance of the feedback systems. A conceptual model is first used to indicate the potential sources of the coupling, how the coupling manifests itself, and how the magnitudes of these critical coupling terms are used to quantify the effects of the airframe/engine interactions. A case study is also presented involving an unstable airframe with thrust vectoring for attitude control. It is shown for this system with classical, decentralized control laws that there is little airframe/engine interaction, and the stability and performance with these control laws is not effected. Implications of parameter uncertainty in the coupling dynamics is also discussed, and effects of these parameter variations are also demonstrated to be small for this vehicle configuration.

TITLE Engines and Artificial Intelligence

INDEX NO. 02TEC.83SCT-TED

AUTHOR Len Buckwalter

PUBLISHER Avionics
DATE February, 1986
DOC TYPE Magazine Article

ABSTRACT
GEN-X is a software package that enables experts, possessing just a basic familiarity with computers, to devise their own systems by inputting their knowledge and experience for troubleshooting. The first application of this software was computerizing the troubleshooting of locomotives in railroad service shops. Other early applications include maintaining the pitch control of the F-15 flight control system and diagnosing gas turbine faults.

TITLE Propulsion System-Flight Control Integration-Flight Evaluation and Technology Transition

INDEX NO. 03TEC.84SCT-TED

AUTHOR F.W. Burcham, G.B. Gliyard, L.P. Myers; NASA Ames Research Center, Dryden Flight Research Facility

PUBLISHER American Institute of Aeronautics and Astronautics, Inc.

DATE July, 1990

DOC TYPE Conference Paper

ABSTRACT

Integration of propulsion and flight control systems and their optimization offers significant performance improvements. The NASA Ames Research Center, Dryden Flight Research Facility has, over the years, conducted research programs which have developed new propulsion and flight control integration concepts, implemented designs on high-performance airplanes, demonstrated these designs in flight, and measured the performance improvements. These programs, first on the YF-12 airplane, and later on the F-15, have demonstrated increased thrust, reduced fuel consumption, increased engine life, and improved airplane performance; with improvements in the 5- to 10-percent range achieved with integration and with no changes to hardware. The design, software and hardware developments, and testing requirements have been shown to be practical. This technology has been transferred to the user community through reports, symposia, and industry cooperative programs, and is appearing on operational and advanced airplanes. The flight evaluation and demonstration have been shown to be key in maturing the technology and hastening its transition into production.

TITLE Oil Debris Monitoring

INDEX NO. 04TEC.85SCT-TED

AUTHOR H.M. Belman; Tedeco Division, Aeroquip Corporation

PUBLISHER Avionics

DATE February, 1986

DOC TYPE Magazine Article

ABSTRACT

Failure of mechanical systems such as transmissions is usually preceded by an increase in the number and size of particles in the lubricating oil. Four types of sensors for detecting these particles are discussed in this article. With a collector sensor a magnet is withdrawn for inspection periodically. The second type of sensor, an electric detector, resembles a spark plug. A particle shorts the detector and in fact the sensor can detect one particle. The third type of sensor, a pulsed electric detector, is similar to the second sensor, but small particles are periodically blown away by a current pulse. The sensor can count small particles, but the sensor fails with a big particle. The final sensor is a quantitative debris monitor (QDM), which magnetically counts and sizes particles. This sensor provides the best results, but with the most cost.

TITLE Vibration Monitoring

INDEX NO. 05TEC.86SCT-TED

AUTHOR J. Higgins, Charles Witt; Endevco Corporation

PUBLISHER Avionics
DATE February 1986
DOC TYPE Magazine Article

ABSTRACT
Vibration monitoring of a turbine engine is a problem since a turbine engine produces mechanical vibration amplitudes at virtually all frequencies in the audio range. A vibration monitoring system must discriminate between engine vibration at frequencies of interest and vibration at other frequencies. The monitoring problem is compounded by the fact that vibration frequencies from a turbine engine are not constant; as power increases or decreases, rotating elements correspondingly change speed. Simple vibration monitoring systems, therefore, are often designed to accept any signals within the operational speed of the engine. An efficient system accepts signals from engine tachometers which then control the center frequency of the bandpass tracking filters. A filter which can track frequencies of interest does not need to be very wide in frequency and is very effective in rejecting unwanted vibration signals.

TITLE The Application of an Expert Maintenance and Diagnostic Tool to Aircraft Engines

INDEX NO. 01GEN.87SCT-TED

AUTHOR Dr. R.L. De Hoff, L. Miller, J. Frenster; Systems Control Technology, Inc.

PUBLISHER American Institute of Aeronautics and Astronautics, Inc.
DATE July, 1990
DOC TYPE Conference Paper

ABSTRACT

Next generation aircraft and engines will have the capability to detect, isolate, and accommodate failures in components and subsystems while in flight. To completely realize the full benefits of weapon system integrated diagnostics, intelligent systems must be developed to assist maintenance personnel in servicing the aircraft efficiently and correctly while on the ground.

This paper describes experiences gained in developing and fielding expert maintenance and diagnostics systems for modern aircraft engines. Specifically, SCT's eXpert MAiNtenance tool (XMAN ™) has been developed for several USAF and USMC engines. The architecture and functionality of XMAN are discussed and its applicability to future engines is presented. Lessons learned are derived which address issues of knowledge acquisition, maintenance training, and insertion into the logistics support infrastructure.

TITLE EPAMS - Engine Performance Assurance Monitoring System

INDEX NO. 02GEN.88SCT-TED

AUTHOR Howell Instruments, Inc.

PUBLISHER Howell Instruments, Inc.
DATE September, 1988
DOC TYPE Product Brochure

ABSTRACT

The microprocessor-based H598 EPAMS monitors engine parameters constantly during all flight operations while calculating theoretical engine parameters for flight conditions as a basis of comparison to actual performance and performs real-time analysis of engine operation.

EPAMS provides the following engine documentary data: engine usage, mission profiles, parts-life tracking, and an automatic history of all limit exceedances. EPAMS will record the number of engine starts, time at maximum power, time above selected levels of performance for up to 22 different values, total engine time, and engine cycles. EPAMS will also detect engine misuse or abuse through its data logging ability.

TITLE On Condition Engine Monitoring

INDEX NO. 03GEN.89SCT-TED

AUTHOR G. Tonnison; Basingstoke Division, Smiths Industries

PUBLISHER Avionics
DATE February, 1986
DOC TYPE Magazine Article

ABSTRACT
Currently, aircraft engines are scheduled for overhaul rather than having maintenance performed "on condition". "On condition" maintenance requires that equipment be removed for overhaul when specified deterioration is identified. Engine monitoring could reduce the risk of "on condition" maintenance to acceptable levels. Systems exist for aircraft engine monitoring as well as for rotary wing aircraft. A typical monitoring system provides facilities in six broad groups: life usage and exceedance; performance- data recording; incident recording; vibration analysis; BITE; and external communications. From these facilities, several analyses are available: low cycle fatigue (LCF), thermal fatigue; creep; time/temperature; time speed; gas path analysis; and oil debris monitoring.

TITLE Helicopter Operators Forecast Steady Growth into Mid-1990s

INDEX NO. 04GEN.90SCT-TED

AUTHOR N.C. Kernstock

PUBLISHER Aviation Week & Space Technology
DATE February, 1990
DOC TYPE Magazine Article

ABSTRACT
The global civil helicopter industry has experienced a rebound, although business has not yet returned to the high levels seen in the late 1970s. Four operators typify those who are achieving success by controlling the growth of existing business and their entry into new markets, as well as exploiting profitable niches. While these companies' operations encompass a wide variety of helicopter missions, three major markets are responsible for most of the growth: the oil industry, police and public service, and medical flight service.

TITLE Osprey's VSLED: Rewriting the Maintenance Manual

INDEX NO. 05GEN.91SCT-TED

AUTHOR E.W. Bassett

PUBLISHER Rotor & Wing International
DATE June 1988
DOC TYPE Magazine Article

ABSTRACT

The Vibration, Structural Life and Engine Diagnostic System (VSLED) is the aircraft health-monitoring system under development for the V-22 Osprey. VSLED consists of an airborne unit and a sensor network. The airborne unit is built around a MIL-STD-1750 processor and two co-processors. The sophisticated and extensive sensor network puts VSLED in touch with engine and airframe components.

TITLE TRENDKEY

INDEX NO. 06GEN.92SCT-TED

AUTHOR Keystone Helicopter Corporation

PUBLISHER Keystone Helicopter Corporation
DATE 1987
DOC TYPE Product Brochure

ABSTRACT

TRENDKEY is a self-contained panel-mounted system that provides operators with a real-time display of aircraft performance during all flight operations. TRENDKEY can also be interfaced with other avionics and systems to monitor, analyze, and display fuel, air data and navigational information.

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